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The Development of Canadian Marine Environmental Quality Guidelines

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Abstract

Marine environmental quality (MEQ) guidelines for physical, chemical, and biological variables have been recommended and used by various jurisdictions around the world. The available information on these guidelines is compiled in this publication, and the respective approaches used to derive them are evaluated. Recommendations are made to set the course for deriving scientifically sound MEQ guidelines for water and sediment in Canada.

Résumé

De nombreux États dans le monde ont formulé et utilisé des recommandations pour la qualité de l'environnement marin (QEM), qui portent sur les variables physiques, chimiques et biologiques. Les informations disponibles sur ces recommandations sont compilées dans la présente publication, et on y évalue les diverses méthodes utilisées pour les formuler. On trouve également des propositions visant à établir un cadre pour l'élaboration de recommandations QEM scientifiquement fondées pour l'eau et les sédiments marins au Canada.

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Executive Summary

Many of Canada's coasts and estuaries currently receive significant loads of anthropogenic substances that can potentially threaten the quality of these environments. In many locations, extensive and biologically significant contamination of coastal resources has already demonstrated the need for remedial action. The growing amount of compelling scientific evidence shows that past decisions on the use of coastal resources have been made in an *ad hoc* manner and have been neither rational nor scientifically based. This approach is no longer acceptable.

The Canadian Environmental Protection Act (CEPA), passed in June 1988, provides the national authorities for the conservation and protection of the marine environment. The formulation of marine environmental quality (MEQ) guidelines is part of the functions and duties described in Parts I and VI of the Act. The United Nations Environment Program (UNEP) "Montreal Guidelines," adopted in principle by Canada in 1985, provide the global framework for protection of marine ecosystems against pollutants from land-based sources. This framework recognizes the various uses of the marine environment and details control strategies required to protect, preserve, and enhance the quality of the marine environment. One of the key strategies is to develop MEQ guidelines, objectives, and standards. This activity was also one of the main recommendations of the 1988 Canadian Conference on Marine Environmental Quality.

MEQ guidelines will provide the scientific and technical information required by resource managers to assess the existing state of the marine environment and to maintain a high level of environmental quality during its intended uses. Such guidelines will also provide the basis for developing site-specific objectives. In addition, MEQ guidelines will be used to identify and focus cleanup operations of contaminated sites. Further, these guidelines will form a scientific basis for making management decisions related to industrial and municipal effluent quality requirements and ocean dumping activities.

MEQ guidelines for physical, chemical, and biological variables have been recommended and used by various jurisdictions around the world (presented in Appendices A to G). In some cases, these guidelines may be adopted on an interim basis for Canadian marine waters. However, application of these guidelines to Canadian conditions requires great care because of potential differences in the sensitivities of native biota and in the environmental pathways and fate of contaminants in the Canadian environment. The applicability of other jurisdictional MEQ guidelines must be validated before they are adopted for Canadian marine ecosystems.

The available information on MEQ guidelines and the respective approaches used to derive them were evaluated in this report. The following recommendations were drafted to set the course for deriving scientifically sound Canadian MEQ guidelines for water and sediment:

(1) The MEQ guidelines from other jurisdictions compiled in this report should be evaluated for their applicability to Canadian conditions and adopted if deemed suitable.

(2) Development of new Canadian MEQ guidelines for water should proceed using the established protocol of the Canadian Council of Ministers of the Environment (CCME).

(3) A formalized protocol for the development of new Canadian MEQ guidelines for sediments should be established and submitted to the CCME for approval. In the interim, the proposed tiered system is recommended using the effects-based, equilibrium partitioning, and background methods.

(4) The biological effects data base, developed by the National Status and Trends Program of the National Oceanic and Atmospheric Administration (NOAA), should be obtained and the data validated. New contaminated sediment/biological effects information and relevant Canadian data should be incorporated into NOAA's data base.

(5) A prioritized list of variables requiring MEQ guidelines for water and sediment should be compiled for Canadian marine ecosystems.

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INTRODUCTION

Canada relies on its coastal waters to provide a variety of economic and social benefits for its people. Coastal ecosystems in Canada (including marine, near-shore, and estuarine environments) support some of the most productive fisheries in the world—a variety of sport, commercial, and subsistence fisheries that contribute significantly to our national economy and identity. Aquaculture has only recently begun to demonstrate its full potential in Canada, yet it has already resulted in tangible economic benefits, including the revitalization of many coastal communities. Our marine environment provides essential transportation links and vast reserves of mineral and petroleum resources that contribute to our economic prosperity. In addition, maritime areas offer a diverse array of unique recreational opportunities (such as sailing, whale-watching, or walking on the beach) that attract millions of visitors to our coasts annually.

Our coastal waters have been generally perceived as having inexhaustible capacities to assimilate a variety of substances and wastes produced by human activities. The result of this perception has been the significant contamination of estuarine, near-shore, and marine ecosystems by a variety of land-based activities, despite the apparent economic and environmental benefits associated with the uses of these areas. Even Arctic ecosystems, which are largely removed from major industrial developments, are starting to exhibit the effects of human activities (Packman and Shearer 1988). A summary of the nature and perceived significance of marine contamination of Pacific, Atlantic, and Arctic waters from land-based sources is provided in Table 1 (Waldichuk 1988).

One of the most significant activities with respect to marine environmental quality involves the ocean disposal of anthropogenic wastes (termed ocean dumping). Dredged sediments and related substances account for the largest proportion of the materials destined for ocean disposal. Dredging and relocation of sediments contaminated with metals and a variety of organic pollutants (e.g., chlorophenols, polychlorinated biphenyls [PCBs], polycyclic aromatic hydrocarbons [PAHs], and organochlorines) can lead to the degradation of coastal ecosystems (Table 2; Waldichuk 1988).

In Canada, discharges of wastes from mining activities on both the Pacific and Atlantic coasts have resulted in contamination of a variety of estuarine and coastal ecosystems. The direct disposal of mine tailings into these waters may result in physical (e.g., smothering of benthic organisms), chemical (e.g., elevated levels of metals, PAHs, and other contaminants in water and sediment), and biological (e.g., acute toxicity, chronic toxicity) effects (Waldichuk 1988).

For many years, the perceived dilution capacity of the marine environment has been used as a viable alternative to proper sewage treatment in many urban centres. Discharges of treated and untreated sewage are major sources of contamination of marine eco-

Table 1. Summary of Land-based Sources of Marine Contamination on Canada's Three Coasts

Contaminant or activity	Atlantic	Pacific	Arctic
Sewage	XXX	XXX	XX
Urban and agricultural runoff	XXX	XXX	X
Pulp and paper mill wastes	XXX	XXX	—
Mining wastes	XX	XX	XX
Ocean dumping	XX	X	X
Coastal developments	XX	XX	XXX
Petroleum hydrocarbon exploration and exploitation	(XX)	(XX)	(XXX)
Agriculture (nutrients, siltation)	X	X	—
Pesticides in agriculture and forestry	XX	X	—
Petroleum refineries	XX	XX	—
Chemical industries (e.g., chlor-alkali plants)	X	X	—
Chemical spills and leaks from shore installations	X	X	X
Atmospheric emissions	X	X	XX
Litter	XX	XX	XX

Source: Waldichuk 1988.

X = ranking of various sources of contaminants in accordance with their perceived importance

( ) = potential

Table 2. Marine Environmental and Ecological Effects of Different Types of Contaminants and Activities

Contaminant or activity	Bacterial/viral contamination	Oxygen depletion	Toxicity	Bioaccumulation	Habitat degradation	Living resources stock depletion	Aesthetics
Sewage	•	•		•	•		•
Urban and agricultural runoff	•	•		•	•		
Pulp and paper mill wastes	•	•	•		•		•
Mining wastes			•	•	•	•	•
Ocean dumping	•	•	•	•	•		
Coastal developments	•				•	•	•
Petroleum hydrocarbon exploration and exploitation		•	•	•	•		•
Agriculture	•	•	•	•	•		•
Pesticides			•	•			
Petroleum refineries			•	•			•
Chlor-alkali plants			•	•			
Chemical spills and leaks		(•)	•	•			•
Atmospheric emissions	•		•	•			
Food and beverage processing		•			•		•
Litter					•	•	•

Source: Waldichuk 1988.

( ) = potential

systems in Canada (Uthe and Zitko 1988; Langford et al. 1988). The impacts of sewage discharges can vary significantly, with specific effects including depressed dissolved oxygen levels, deposition of organic matter in the vicinity of outfalls, bacteriological contamination of recreational and shellfish growing areas, and elevated levels of metals and other pollutants.

Industrial effluents can contribute a diverse array of toxic compounds to estuarine and near-shore areas. Pulp mill effluents can cause adverse effects on marine ecosystems due to the presence of suspended solids and oxygen-demanding materials, resin acids, and a variety of chlorinated organic compounds (including dioxins and furans). Metals, nutrients, and halogenated compounds may also be present in the effluents from the metal plating, petrochemical refining, metallurgical, textile, chlor-alkali, wood preserving, and chemical manufacturing industries (Waldichuk 1988).

Non-point source pollution can be attributed to agricultural activities, uncontrolled urban and industrial runoff, and deposition of airborne materials. Losses of fertilizers, herbicides, insecticides, and other biocides from agricultural lands can result in contamination of nearby watercourses (Heath 1987). Riverine transport is known to occur for these substances, as well as those arising from urban and industrial runoff. However, the specific sources, quantities, and final fate of these compounds in Canadian marine environments have not been investigated to date. Further, the deposition of pollutants transported by atmospheric systems may impose additional stresses on marine environments.

A serious threat to the quality of marine environments is associated with the exploration, development, and transport of petroleum resources. Recent experiences in the Gulf of Alaska (the 1989 Exxon Valdez spill) and the west coast of Vancouver Island (the 1988 Nestucca spill) clearly demonstrate the potential for catastrophic effects of oil spills on coastal ecosystems (Anderson 1989). The economic and social effects of these spills will not be fully understood for many years. However, follow-up studies in the vicinity of the Amoco Cadiz spill off the coast of France have suggested that these effects are likely to be significant and long-term (i.e., greater than 10 years). The extreme sensitivity of the Canadian Arctic and the dependence of native and coastal populations on marine resources make the potential for large-scale contamination by petroleum hydrocarbons particularly threatening (Packman and Shearer 1988).

Activities associated with the marine transport of manufactured goods and other products may adversely affect coastal ecosystems through a variety of mechanisms. The most common problems associated with marine transport include chemical (e.g., fuel or other toxic substances) spills, discharge of waste products (e.g., garbage and human wastes), and the recent introduction of non-native organisms (e.g., the

zebra mussel in the Great Lakes and St. Lawrence basin) through the discharge of ballast water.

Conservation and protection of Canada's coastal ecosystems and maintenance of a high level of marine environmental quality have been identified as priority management goals in recent years (Marine Environmental Quality Advisory Group 1987; Wells 1988; Cote 1989). However, achievement of these goals requires the use of practical tools to assess the quality of the marine environment. Managers responsible for marine environmental quality in Canada need information on the fate and effects of specific chemicals in the marine environment. Therefore, marine environmental managers have an immediate need for environmental quality guidelines applicable to water and sediment in coastal ecosystems in Canada. The present report is intended to serve as a discussion document that may be used to further develop the strategy for the implementation of marine environmental quality (MEQ) guidelines in Canada. A compilation of MEQ guidelines currently in use in various jurisdictions around the world is provided in Appendices A to G.

BACKGROUND AND DEFINITIONS

In Canada, coastal ecosystems support a variety of biologically, economically, and culturally important water uses. In addition to these designated uses, our coastal waters are used as sinks for domestic, agricultural, and industrial waste products (from both point and non-point sources) that can contaminate coastal ecosystems and potentially compromise water uses. The responsibility of water resource managers is to consider the interests and needs of the various users in order to ensure that coastal resources are used wisely and to the greatest common benefit of all Canadians.

As a signatory to the United Nations Environment Program (UNEP) Agreement for the Protection of the Marine Environment Against Pollution from Land-Based Sources (the 1985 UNEP "Montreal Guidelines"), Canada has embraced, in principle, the need to develop a national framework for protecting the quality and intended uses of the marine environment. The aim of the UNEP agreement is to strengthen arrangements to ensure the harmonization and application of global and regional guidelines and standards (UNEP 1985). The need for MEQ guidelines or standards was identified in two of the three main pollution control strategies described in the agreement for effective control of major land-based discharges to coastal and estuarine ecosystems. This need was also identified as one of the major components of a practical approach to marine environmental protection at the 1988 Canadian Conference on Marine Environmental Quality (Wells and Gratwick 1988).

The Canadian Environmental Protection Act (CEPA), passed in June 1988, provides the national authorities for the protection and conservation of Canadian marine environmental quality (Cornwall et al. 1988). The need for MEQ guidelines and objectives is identified in Part I of the Act. In addition, sediment quality guidelines are urgently required for the development of CEPA Part VI regulations. These guidelines will provide basic scientific and technical information on the influence of environmental quality variables on the uses of the marine environment. This information can then be used to assess MEQ issues and concerns and to establish site-specific environmental quality objectives.

The use and interpretation of the terms criteria, guidelines, objectives, and standards vary among the individual agencies involved in regulating environmental quality. With respect to the MEQ guidelines development process in Canada, the following definitions will be used:

(1) *Criteria*—These are the scientific data that are evaluated to derive the recommended limits for the uses of the marine environment. For example, the 96-h LC_{50} of zinc to the mysid shrimp, *Mysidopsis bahia*, has been reported to be 0.499 $mg \cdot L^{-1}$ (Suter and Rosen 1988).

(2) *Guidelines*—These are numerical concentrations or narrative statements recommended to support and maintain designated uses of the marine environment. For example, no harmful effects on mysid shrimp will result if the maximum concentration of zinc remains below 0.166 $mg \cdot L^{-1}$ (Suter and Rosen 1988).

(3) *Objectives*—These are numerical concentrations or narrative statements that have been established to support and protect the designated uses of the marine environment at a specified site. For example, the average concentration of zinc in the Fraser River estuary *should not* exceed 0.050 $mg \cdot L^{-1}$ to protect sensitive fish and aquatic life species and, in so doing, should ensure that other beneficial uses are not impaired (Swain and Holms 1985).

(4) *Standards*—These are MEQ objectives that are recognized in enforceable environmental control laws of a level of government. For example, the

average concentration of zinc in the Columbia River basin *shall not* exceed 0.086 $mg \cdot L^{-1}$ (Oregon Department of Environmental Quality 1989a).

The intent of MEQ guidelines is to provide the scientific information necessary to define conditions that will protect and maintain the marine environment, including estuarine, near-shore, and marine ecosystems in Canada, in the context of the designated uses of these resources. The MEQ guidelines will contain recommendations for physical, chemical, biological, and radiological variables for this purpose. The water uses are those associated with aquatic life and their habitats, the wildlife associated with these areas, mariculture, recreation and aesthetics, and the protection of human health. There are other valid uses of the marine environment, such as power generation, storage, waste assimilation, industrial supplies (process water), and transportation, but these are likely to be less sensitive than the water uses listed above.

The development of MEQ guidelines for the protection of a given use is done independently of other uses. Therefore, the guideline is not influenced by such factors as availability and cost of control or remedial measures. With respect to a particular variable of concern, the guideline developed for the most sensitive use would govern the management or input of this variable. It is generally recognized that if the environmental quality is maintained to protect living marine resources in a viable, healthy ecosystem, then it will also be adequate for other uses of the marine environment.

The Canadian MEQ guidelines are to be used as reference points for identifying and assessing the potential impacts of environmental quality variables on the uses of the marine environment. In addition, MEQ guidelines will be used to identify and focus cleanup operations of contaminated sites. They will also form a scientific basis for making management decisions related to industrial and municipal effluent quality requirements and ocean dumping activities. However, these MEQ guidelines should not be regarded as "blanket values" for marine environmental quality. Where a potential problem is identified, more detailed assessments must be carried out on a site-specific basis to determine the extent of the problem and whether appropriate remedial action is required.

The guidelines will contribute to the effective management of Canada's marine resources by providing scientific and technical information for the derivation of site-specific MEQ objectives. In addition to this information, knowledge of the specific environmental quality characteristics of the site must be acquired during the derivation of the objective. These include:

(1) the existing levels of particular environmental quality variables at the specific location;

(2) the temporal and spatial variability of water, sediment, and biota characteristics at the site;

(3) the existing and potential aquatic life;

(4) the flow or circulation pattern and its relation to the quality of the water, sediment, and biota;

(5) the existing and potential loadings of contaminants from point and non-point sources; and

(6) the existing and potential uses of the marine environment.

The collection and synthesis of this information form the basis for an assessment of the existing and potential environmental quality at the site. Along with this information, socio-economic factors are also considered during the development of site-specific objectives.

Sound management of our coastal resources is a complex task, requiring integration of the interests of resource user groups with detailed scientific information on the current strength, sensitivity, and value of common property resources. Environmental quality guidelines, objectives, and standards provide the instruments for making scientifically defensible management decisions and for interpreting the toxicological significance of environmental contaminants data necessary for impact assessment, site remediation, and state of the environment reporting. The development of pollution control options respecting the quality of the receiving marine environment can be implemented only if scientific criteria on the potential impacts of pollutants on marine life along with environmental quality guidelines for water and sediments are available. Therefore, the formulation and implementation of a process to develop Canadian MEQ guidelines are now urgently required in order to effectively manage Canada's marine ecosystems in the future.

MARINE WATER QUALITY GUIDELINES

Concerns over the quality of marine water resources have increased the demand for information on the state of coastal and estuarine ecosystems. Although regulatory agencies have collected great quantities of data on the chemical characteristics of coastal waters, the biological significance of these data remains largely unclear. Numerous jurisdictions in the world employ water quality guidelines as a means of assessing the quality of coastal and estuarine waters, as a basis for making decisions on the management of these areas, and as a scientific basis for the establishment of site-specific water quality objectives (and standards, where appropriate). The approaches that have been or may be used to formulate quality guidelines for coastal waters are summarized in the following sections and include the following:

(1) water background (WB) approach;

(2) theoretical toxicological (TT) approach;

(3) modified toxicological (MT) approach;

(4) spiked bioassay (SBA) approach; and

(5) Canadian Council of Ministers of the Environment (CCME) approach.

Water Background (WB) Approach

In the water background approach, a data base is assembled on the concentrations of contaminants in water at reference background sites that are deemed to have acceptable water quality. In British Columbia and Atlantic Canada, relatively large water quality data bases already exist from feasibility studies (undertaken in support of site selection for aquaculture operations), baseline water quality studies, and other special studies. Statistical manipulations of these data (e.g., geometric mean, percentile estimation, log mean) are available for each water quality variable and provide a means of defining background levels at sites that currently support designated water uses. In theory, background levels of strictly man-made compounds, such as many of the halogenated organic contaminants, should be zero. Guidelines may then be developed that specify no or slight increases above pre-developmental (where these data exist) or reference background levels. Although it is rarely stated explicitly, it is likely that this approach has been used implicitly to make the majority of decisions on how water resources are to be used in marine ecosystems around the world.

Theoretical Toxicological (TT) Approach

The theoretical toxicological approach to the development of water quality criteria, guidelines, objectives, and standards essentially involves assessment of the relevant literature on the toxicology of a substance in an effort to define safe or no-effect levels in the environment. This approach has been adopted by many of the jurisdictions that have proposed water quality guidelines. The formalized approach, which was developed by the U.S. Environmental Protection Agency (EPA) (Stephan et al. 1985), clearly illustrates this process (Fig. 1).

The preliminary step in the guidelines (termed criteria by the U.S. EPA) development process involves a cursory analysis of the literature with respect to the aqueous chemistry of the element or compound of interest. During this step, general information on the chemical's formula, molecular weight, melting point, vapour pressure, and physical state is collected. Further, its dissociation constant, solubility in various solvents, octanol/water partition coefficient, and other related data are documented to provide a means of predicting the substance's aqueous behaviour. Standard procedures for sample collection, transport, and analysis are also reviewed and assessed for compatibility with those that have been used in the toxicity studies reported in the scientific literature.

The second stage in the process involves extensive review of the scientific literature to facilitate compilation of all of the available data on:

(1) acute toxicity to aquatic plants and animals;

(2) chronic toxicity to aquatic plants and animals;

(3) bioaccumulation in aquatic plants and animals;

(4) Food and Drug Administration (FDA) action levels for edible tissues; and

(5) chronic effects on consumers of aquatic organisms.

These data are then assessed to determine their appropriateness for use in the guidelines development process. Critical factors to be considered include the presence and adequacy of control tests, the chemical formulation, and the dilution water type (e.g., tests

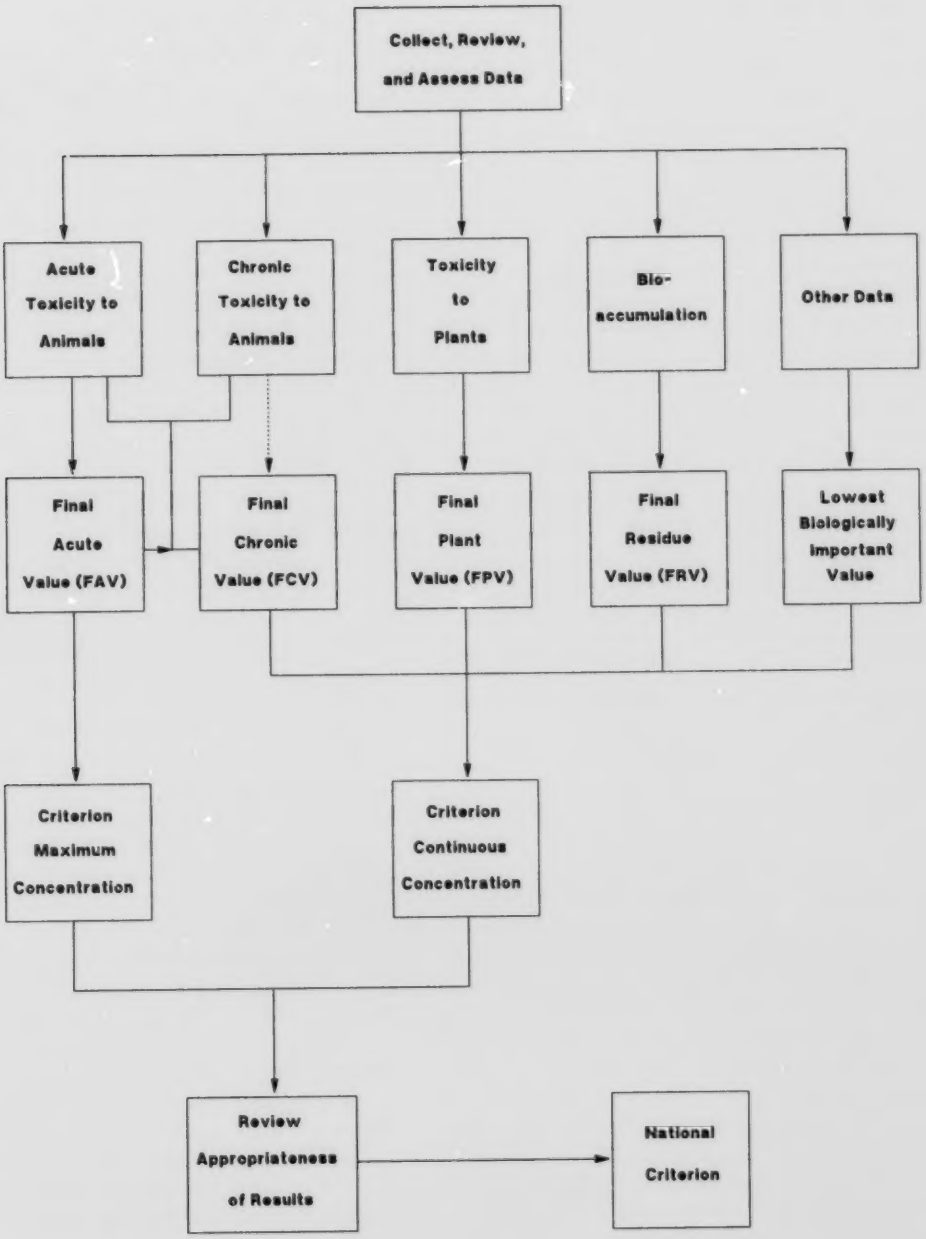

Figure 1. Theoretical toxicological (TT) approach.

run using distilled or deionized water are not acceptable). The type of test used in the bioassay is compared with the nature of the substance being tested (e.g., flow-through tests should be used with highly volatile substances). In addition, information on the test organism, such as pre-exposure to toxic substances, geographic distribution, and applicability to North American ecosystems, is reviewed before the data are accepted for use in the guidelines derivation process.

The data requirements for the formulation of water quality guidelines have been explicitly addressed to ensure consistency in the final product. The U.S. EPA requires acute toxicity data for species representing at least eight families of marine organisms, including at least two families of chordates, five families of invertebrates, and one other family. Information on chronic effects on one fish species, one invertebrate species (these can be freshwater species), and one sensitive marine species is required to calculate acute to chronic ratios (ACRs). Further, information must be available on bioaccumulation in an appropriate marine species and on responses of at least one marine alga or vascular plant.

Appropriate measures of the acute toxicity of a substance to a variety of marine species are used to calculate the final acute value (FAV). The FAV is an estimate of the concentration of the substance corresponding to the 5th percentile of the acute toxicity values for all of the genera for which acceptable acute tests have been conducted.

The FAV of a substance is calculated in the following manner. For each species for which at least one acute value is available, the species mean acute value (SMAV) is calculated as the geometric mean of acceptable test results. For each genus for which one or more SMAVs are available, the genus mean acute value (GMAV) is calculated as the geometric mean of the available SMAVs. The GMAVs are then ranked from lowest to highest, and the cumulative probability for each GMAV is calculated. The FAV is subsequently calculated using the lowest four GMAVs and their cumulative probabilities. If the SMAV of a commercially or economically important species is lower than the calculated FAV, the SMAV replaces the FAV to provide protection for that species.

When enough acute data are available to demonstrate that the toxicity of the substance to two or more species is dependent on a specific characteristic of the dilution water, then derivation of a final acute equation (FAE) is warranted. This procedure requires that the relationship between toxicity and water quality be quantifiable using standard statistical methods. The most common water characteristic/toxicant relationships in marine environments involve salinity and temperature, but others are certainly possible.

The final chronic value (FCV) may be calculated in a manner consistent with the derivation of the FAV if sufficient acceptable data on the chronic toxicity of the substance are available. An alternate approach to calculating the FCV is to divide the FAV by the ACR. In situations in which chronic toxicity is dependent on one or more water quality characteristics, it may be necessary to derive a final chronic equation (FCE).

Derivation of a final plant value (FPV) provides a means of comparing the relative sensitivities of marine plants and animals. In general, the available data on the inhibition of growth or photosynthesis are compiled and analyzed to provide estimates of effect levels of a substance on marine plants. The FPV is obtained by selecting the lowest level from studies using an important marine plant species in which the concentration of the toxicant was measured and the end point was biologically important.

Derivation of a final residue value (FRV) is undertaken to ensure that the final guidelines address the potential for bioaccumulation of harmful levels of a substance in the marine organisms that are consumed by humans or other predatory species. The FRV is calculated by dividing the maximum permissible tissue concentration (as defined by the U.S. FDA) by appropriate bioaccumulation factors (BAFs) or bioconcentration factors (BCFs). BCFs are generally determined in laboratory studies and account only for the net uptake of a substance directly from water. BAFs are measured under field conditions and account for the net uptake of a substance from both food and water. Measured BCFs and BAFs may vary by several orders of magnitude, depending on the nature of the substance and its fate in aquatic ecosystems. Stephan et al. (1985) provided specific guidance on how to calculate BCFs and BAFs for both hydrophilic and lipophilic substances.

The final guidelines for a substance in water consist of two concentrations: a short-term maximum concentration and a long-term mean concentration. The FAV or FAE is used to calculate the maximum permissible concentration of the substance in water. In general, the guideline for short-term exposure (i.e., criterion maximum concentration) is derived by mul-

tiplying the FAV or FAE by 0.5. The lowest of the FCV, FPV, and the FRV values is used directly to establish the long-term mean concentration (i.e., criterion continuous concentration). These guidelines are then reviewed to ensure that they were developed in a manner consistent with the recommended formalized procedure before they are adopted as national criteria.

The major advantage of the theoretical toxicological approach is that the procedure is highly formalized and therefore reproducible and scientifically defensible. Disadvantages of this approach are primarily associated with the large toxicological data base required to derive guidelines. These data are not available for many variables, and it is therefore not possible to recommend guidelines for those variables. In these situations, the U.S. EPA may issue Water Quality Advisories for specific compounds, which may be derived using smaller and less rigid data sets (see Hansen 1989 for details). There is also some question about the level of protection afforded aquatic biota by guidelines that are equivalent to the FCV. Species more sensitive than the ones tested would likely be adversely affected by long-term exposures to FCV levels. In addition, certain classes of biota (e.g., fathead minnows) may be overrepresented in the toxicological data base, thereby skewing the distribution of the data. Therefore, a procedure is required for developing safety factors that are related to the completeness and balance of the data base.

Modified Toxicological (MT) Approach

An alternate approach to the development of water quality guidelines from toxicological data has been adopted by the California State Water Resources Control Board (Klapow and Lewis 1979). This approach was formulated to acknowledge deficiencies in the data base—specifically, the toxicities of environmental contaminants to marine organisms and the responses of natural communities to prolonged exposures to potentially toxic substances.

In this approach (Fig. 2), three types of quantitative data are used in the development of water quality guidelines. Laboratory-based acute toxicity data for both marine and freshwater species, chronic toxicity data for estuarine and marine species, and data on the background levels of naturally occurring substances in seawater are collected from literature sources and assembled in data bases. These data are not subjected to critical evaluations of their validity or applicability to the conditions under consideration for guidelines development. The only criterion for accepting these data is that they must be retrievable from a published source.

The use of both marine and freshwater acute toxicity data in the development of water quality guidelines for saltwater or brackish water systems is contrary to the toxicological dogma that the data used should reflect the tolerance of resident species to environmental challenges. However, statistical analyses of the data revealed no systematic differences in the medians or ranges of acute toxicity values obtained in freshwater or saltwater tests. Therefore, other factors such as variability in the sensitivities of various life stages and species were deemed to be more important than the water quality characteristics for explaining the variation in the data.

Using the available acute toxicity data, a conservative estimate of the acutely toxic concentration is taken as the lower 10th percentile of the LC_{50} data. The chronically toxic concentration of each substance is estimated by taking the log mean of the lowest three chronic and sublethal concentrations reported. An estimate of the average background concentration of each substance is then calculated by taking the log mean of all of the available data. The percentile and averaging procedures recommended are used to minimize the effect of unrepresentative data points on the outcome.

The water quality guidelines are then calculated following the convention recommended in Water Quality Criteria 1972 (NAS/NAE 1973). Using this convention, the acute toxicity values are multiplied by the application factors specified by the NAS/NAE, which range from 0.1 for cyanide to 0.01 for arsenic. If the resulting product falls within the logical range, it is accepted as the water quality guideline. The logical range is defined by the average concentration of the substance in seawater (on the lower end) and the calculated chronic toxicity value (on the upper end). If the product falls outside the logical range, the guideline is set at the midpoint of the logical range. Most of the guidelines calculated for California (10 out of 13 variables) fell within the defined logical range (Klapow and Lewis 1979).

The definition of the logical range is a cornerstone of the modified toxicological approach to the development of marine water quality guidelines. From a regulatory point of view, guidelines falling outside the logical range provide little guidance to resource managers. However, guideline values lying within the range of concentrations known to cause chronic toxicity or sublethal effects are not likely to provide

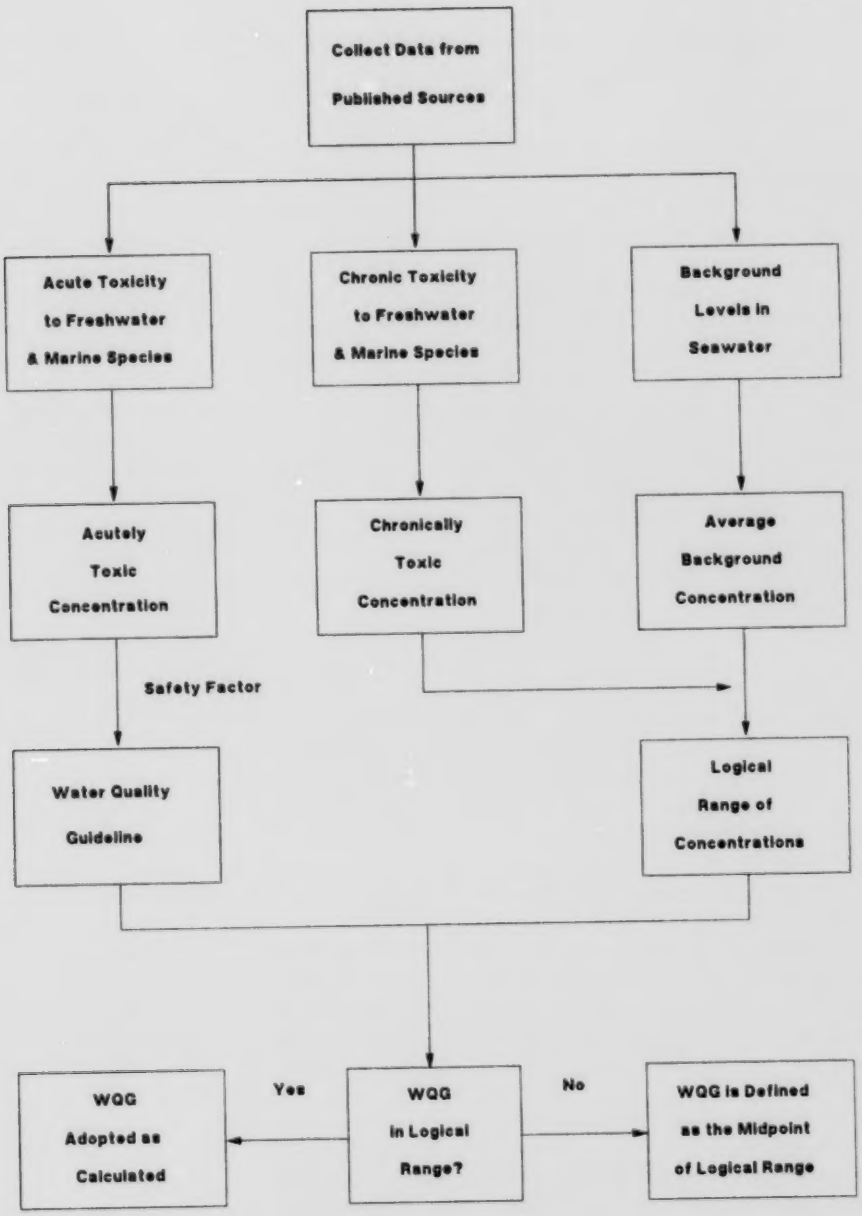
Collect Data from Published Sources
Acute Toxicity to Freshwater & Marine Species
Chronic Toxicity to Freshwater & Marine Species
Background Levels in Seawater
Acutely Toxic Concentration
Chronically Toxic Concentration
Average Background Concentration
Safety Factor
Water Quality Guideline
Logical Range of Concentrations
WQG Adopted as Calculated
Yes
WQG in Logical Range?
No
WQG is Defined as the Midpoint of Logical Range

Figure 2. Modified toxicological (MT) approach.

acceptable levels of protection to marine organisms. It is also unreasonable to set guideline values that are at or below the detection limits of analytical methods available. Therefore, guidelines that fall within a logical range make intuitive sense and are more likely to be valid than guidelines that do not fall within that range or those whose validity has not been tested.

A major shortcoming of this approach is the use of both freshwater and marine toxicity data in the development of water quality guidelines. The influence of water quality characteristics on toxicity has been documented for ammonia (i.e., effects of pH and temperature; Willingham 1988), a variety of metals (i.e., effect of water hardness; Spear and Pierce 1979; U.S. EPA 1985a, 1985b), and pesticides (MacDonald 1989). Hansen (1989) compared the saltwater and freshwater criteria values that have been developed for a variety of substances and noted that almost 50% of the criterion maximum concentrations differed by more than a factor of five. This finding led to the conclusion that separate criteria were required for the protection of marine and freshwater aquatic life.

Spiked Bioassay (SBA) Approach

Theoretical toxicological assessments can provide a great deal of the information required to develop scientifically based water quality guidelines. However, for many water quality variables, there may not be enough aquatic toxicology information to allow a satisfactory assessment. In other cases, the applicability of laboratory studies in assessing ecosystem responses might be questioned. Cairns (1983, 1986a, 1986b) presented a number of convincing arguments for the multi-species or validation approach to environmental toxicology, including the following:

(1) Even the most meticulous single-species laboratory bioassay test cannot accurately predict how several such species might interact competitively or as predator/prey in the natural environment.

(2) As the accuracy of laboratory toxicity tests in predicting actual responses in aquatic ecosystems is generally questionable, safety or application factors are used to adequately protect the resource. This approach can lead to large over- or underestimates of toxic effects in the aquatic environment.

(3) From a holistic point of view, even the "most sensitive species" concept is flawed, because new properties are added to systems as components interact.

The accuracy of predicted responses of aquatic biota to contaminant challenges is greatly increased by knowledge of detailed toxicological information on the system under study. Two specific procedures have been described by the U.S. EPA (1983) to account for variations in local water quality and differences in the sensitivity of resident species. Therefore, the toxicity data that are generated are, necessarily, directly applicable to the site and species under consideration.

The indicator species procedure (Fig. 3) is designed to account for differences in the biological availability and toxicity of a substance that may be attributable to the physical and/or chemical characteristics of the site water. In these bioassays, site water or reconstituted laboratory water is spiked with the contaminant and diluted to various concentrations with parent water. Test species, such as coho salmon and grass shrimp, may be used in these bioassays as indicators of the influence of ambient water quality on toxicity.

The resident species procedure is similar in many respects to the indicator species procedure. The principal difference between the two approaches is that sensitive resident species are used as test organisms to achieve greater resolution and confidence in the guidelines subsequently developed.

Spiked bioassays may be as simple as 4-d static renewal tests using site water to assess acute toxicity to coho salmon smolts. More complex bioassays may be run on resident fish species over their life history to assess long-term chronic effects on sensitive end points, such as reproduction and growth. Even more intricate tests involve the construction of mesocosms or whole-ecosystem manipulation. The main advantage of these tests is that they provide detailed information on the response of aquatic biota to specific contaminant challenges. Therefore, they generate a high level of confidence in the water quality guidelines that are based on the results.

The major disadvantage of this approach is the relatively high costs associated with these studies. However, these expenditures are justified when a great deal of confidence in predictions of responses is required. When aquatic resources are deemed to have exceptional values (such as those associated with the Fraser River estuary) and are put at risk (either

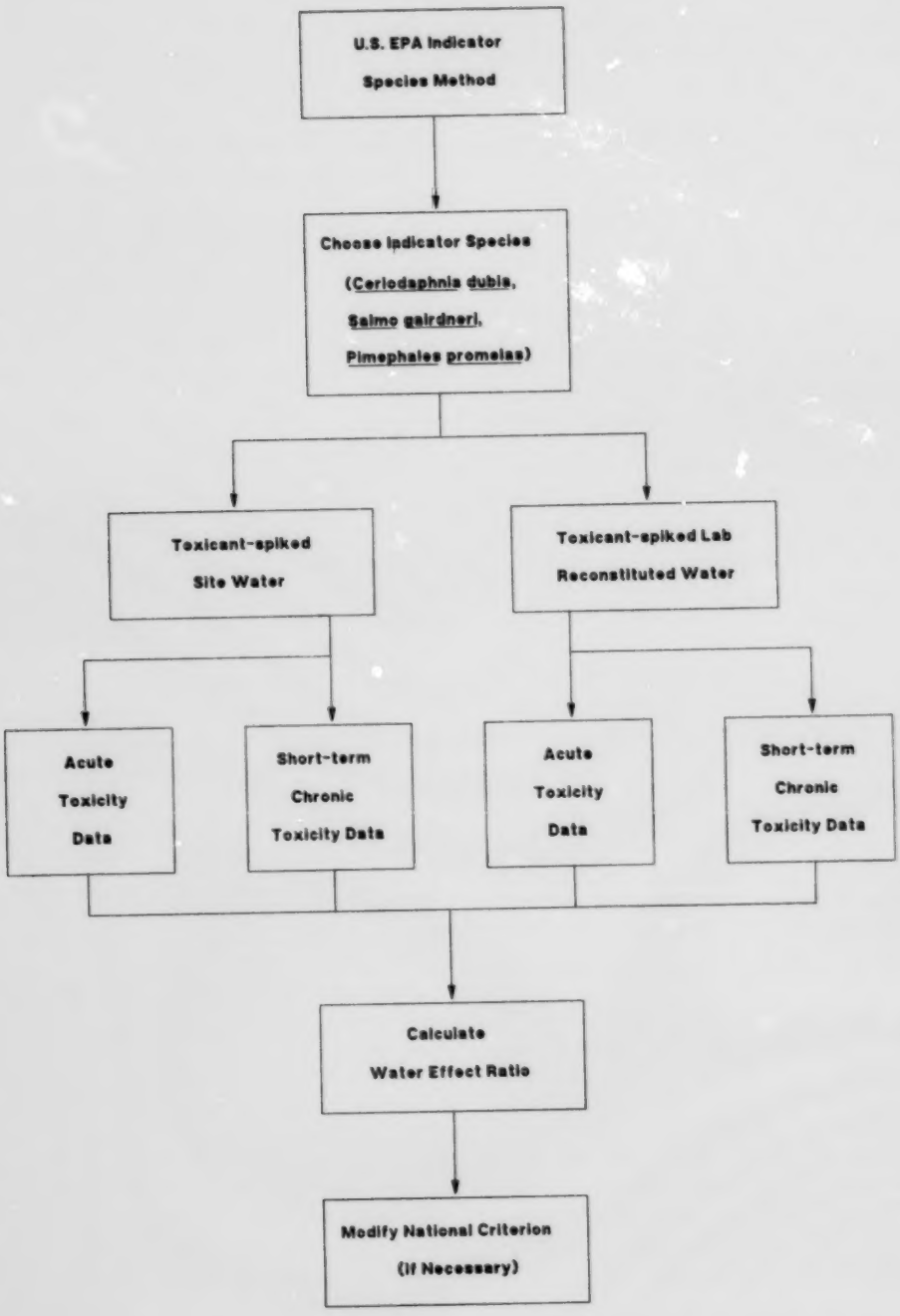

Figure 3. Spiked bioassay (SBA) approach.

real or perceived) by developmental activities, then the costs associated with spiked bioassays may be easily justified.

Canadian Council of Ministers of the Environment (CCME) Approach

The CCME (1990) has developed a formalized protocol for the derivation of water quality guidelines for the protection of freshwater and marine aquatic life. In many ways, the CCME approach is similar to the theoretical toxicological approach described previously. However, there are a number of unique aspects that set the CCME strategy apart from the other effects-based methods for developing water quality guidelines.

The CCME approach is a multi-stepped process (Fig. 4) that calls for the development of two distinct data bases. The first step involves the development of an aquatic toxicity data base. The data collected in this step are consistent with the information collected in the theoretical toxicological approach. The second step involves the development of an environmental fate and occurrence data base. Information on the major environmental fate processes and the persistence in water, soil, sediment, air, and biota of the contaminant under study forms the basis of this data base. The data collected in both of the first two steps are then assessed to ensure that minimum data quality and quantity requirements are met. Derivation of numerical water quality guidelines is possible if the specified minimum toxicity and fate data requirements are satisfied.

In general, guidelines or interim guidelines are derived from the lowest-observed-effect level (LOEL) for the most sensitive life stage of the most sensitive fish, invertebrate, or plant species investigated. Guidelines may be derived from the results of either acute or chronic studies; however, chronic studies with non-lethal end points are preferred. The key study or studies used to derive the guidelines must have demonstrated a clear dose/response relationship, and the LOEL must be statistically significant.

Guidelines are developed from a chronic study by multiplying the most sensitive LOEL by a safety factor of 0.1. This safety factor is designed to account for differences in sensitivity to a chemical due to differences in species, in laboratory vs. field conditions, and in test end points. When available, ACRs are used to estimate a long-term no-effect concentration from the median lethal results of a short-term acute study. In situations in which no data exist on ACRs, guidelines are derived directly from the results of acute toxicity studies. In this case, application factors are used in conjunction with the test results. For persistent (half-life in water > 8 weeks) and non-persistent (half-life in water < 8 weeks) chemicals, the recommended application factors are 0.01 and 0.05, respectively.

The major advantages of the CCME approach are that it is formalized, reproducible, and generally accepted by federal and provincial agencies across Canada. In addition, the approach is conservative enough to ensure that aquatic resources in coastal and estuarine waters in Canada are adequately protected.

An Approach to the Development of Canadian MEQ Guidelines for Water

Compilations of water quality guidelines for the protection of coastal and estuarine biota that have been recommended and used by various jurisdictions around the world are presented in Appendices A and B. Similar compilations of guidelines for the other two major uses of coastal waters—recreation and aesthetics, and industrial water supplies—are presented in Appendices C to F. Many of these guidelines, particularly those developed using the theoretical toxicological and modified toxicological approaches, can be used on an interim basis for making decisions on the management of coastal and estuarine waters. Application of these guidelines to Canadian waters requires great care because of the potential for differences between the sensitivities of Canadian species and those of species addressed in the development of other jurisdictional guidelines. Differences in toxicities of various contaminants due to differences in water quality characteristics must also be considered.

The development of Canadian MEQ guidelines for coastal and estuarine waters should be initiated immediately to provide environmental managers with the information they need to make informed decisions on the use of our coastal waters. The need for these guidelines has become even more critical in the past few years, as recent monitoring activities have clearly indicated degraded environmental quality in many coastal ecosystems. Canadian MEQ guidelines for water ought to focus primarily on the protection of aquatic life and their uses in coastal waters. The other major uses of water in coastal areas are not likely to be as sensitive as aquatic life.

A reasonable first step in the process is to develop a list of priority substances (i.e., water quality variables) for which guidelines are needed immediately. Canadian MEQ guidelines for water should then be

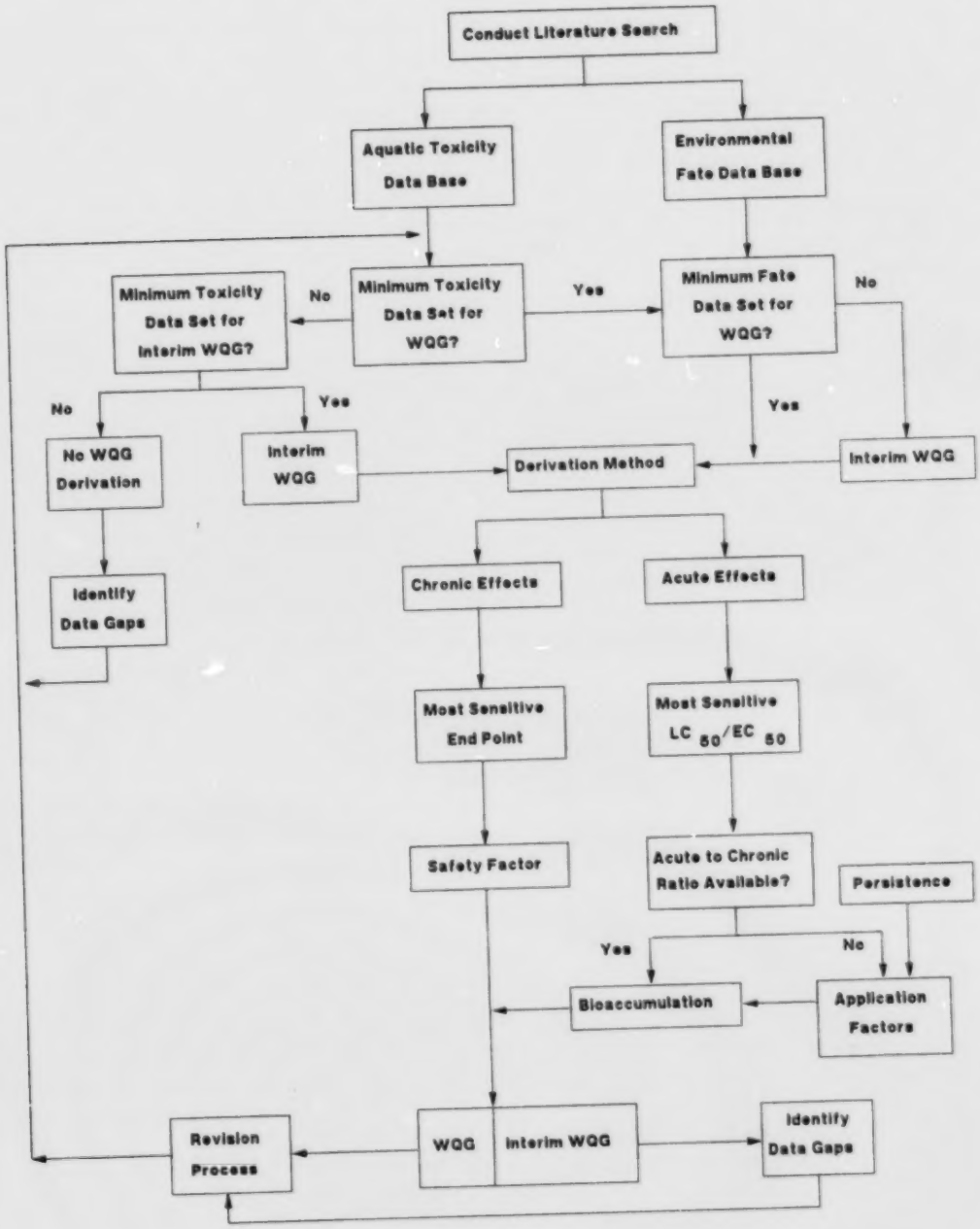

Figure 4. Canadian Council of Ministers of the Environment (CCME) approach.

developed for each priority variable using the approach recommended by the CCME. Consideration should be given to the derivation of working "interim" guidelines for a number of variables from the compilation of guidelines in Appendices A to F. The guidelines that are found to be suitable for Canadian conditions, in that they account for the sensitivities of Canadian species, can be adopted until more detailed assessments are conducted. Data gaps and research needs should be identified for variables for which insufficient data exist for the recommendation of guidelines.

MARINE SEDIMENT QUALITY GUIDELINES

Contaminated sediment has been identified as a major environmental concern in aquatic ecosystems along coastlines of North America (NOAA 1984; IJC 1988). Elevated concentrations of trace and major inorganic elements may occur as a result of an array of natural processes. However, contamination of coastal sediments with inorganic elements and organic contaminants may also occur as a result of the activities of humans. Specifically, pollutants originating from industrial, municipal, and non-point sources (including those that are transported via the atmosphere) can be transported through the water column, can be adsorbed onto suspended solids, and can accumulate in bottom sediments upon deposition. These elevated concentrations of inorganic and organic substances in bottom sediments may result in a range of adverse effects on associated benthic organisms.

Contamination of sediments may affect such activities as dredging, dredge spoil disposal, aquaculture, swimming, habitat protection, fishing, and shoreline rehabilitation. In addition, through the processes of desorption and resuspension, contaminated sediments can act as a significant source of contaminants in areas where the input of chemicals has been eliminated. Furthermore, chemicals released from sediments may be a factor in the contamination of aquatic life and the impairment of the surrounding water quality. To effectively assess sediment contamination problems in a systematic and scientifically based manner, environmental managers require guidelines defining the acceptability of measured contaminant concentrations.

In Canada, there are currently no nationally recognized, ecotoxicologically based guidelines to evaluate the quality of marine sediments. Actual numerical limits applicable to the assessment of marine sediments have been formulated for mercury and cadmium in Part VI (formerly the Ocean Dumping Control Act) regulations of CEPA. However, no documented rationale for these numerical limits is available. At present, there is an urgent need for the development of marine sediment quality guidelines for substances specified under Part VI of CEPA.

Sediment quality guidelines provide a means of assessing the quality of marine sediments. Several approaches have been devised to formulate sediment quality guidelines. These approaches have been reviewed and summarized by Beak Consultants Ltd. (1987, 1988), Chapman (1989), Persaud et al. (1989), and the U.S. EPA (1989a). The following discussion on approaches to the development of sediment quality guidelines has been abstracted from these documents. The various approaches are:

(1) sediment background (SB) approach;

(2) spiked-sediment toxicity (SST) approach;

(3) water quality guidelines (WQG) approach;

(4) interstitial water toxicity (IWT) approach;

(5) equilibrium partitioning (EP) approach;

(6) tissue residue (TR) approach;

(7) benthic community structure assessment (BCSA) approach;

(8) screening level concentration (SLC) approach;

(9) sediment quality triad (SQT) approach;

(10) apparent effects threshold (AET) approach;

(11) sediment assessment strategy recommended by the International Joint Commission (IJC); and

(12) National Status and Trends Program data base (NSTP-DB) approach.

The discussion on each of the approaches has been divided into four main sections—a brief description of the methodology, the major advantages and limitations of the technique, and the current uses of the approach. It should be pointed out that some of the approaches have been investigated extensively, and the discussion of those approaches is therefore rather substantial (e.g., the equilibrium partitioning approach). Other approaches have been used for other purposes (e.g., the interstitial water toxicity approach), such as the assessment of industrial

effluents, and efforts are under way to modify them for use with sediments as the test media. Difficulties were encountered during the collation of information on current uses of several of these approaches because they have been used or are being used to support litigation, and the data have therefore not been made available to the general public.

Sediment Background (SB) Approach

In this approach, sediment contaminant concentrations at an assessment site are compared with the concentrations of these chemicals at a site that is deemed to be representative of the background (natural) conditions. Alternatively, historical records for a specific site or, more appropriately, data from sediment core profiles may be used to define background levels of specific contaminants. Special care must be taken in choosing the location of sampling stations, in sample preparation, in sample analysis methodology, and in quality assurance/quality control. Sediment quality guidelines developed using this approach may specify no or small increases in the concentrations of contaminants above the previously defined background levels.

The major advantages of this approach derive from its simplicity. It relies only on measurements that can be easily made in most analytical laboratories, it provides a means of easily comparing monitoring program results with the guidelines (i.e., it yields chemical concentration values), it does not have extensive data requirements, and it does not require toxicity testing.

The major limitation of this approach is that no direct biological effects data are used in the derivation of guidelines. In addition, this approach applies only to major and trace elements (because natural background concentrations can be identified from core samples or geochemical data). The background concentrations of anthropogenic organic contaminants should be zero, although it is well established that detectable concentrations of many of these contaminants occur as a result of long-range atmospheric transport.

This approach has not been used extensively in the past. On the Great Lakes, it was used by Mudroch et al. (1986, 1988) to identify deficiencies in the Ontario Ministry of the Environment guidelines (Persaud and Wilkins 1976) for evaluating open-water disposal of dredged sediment. The use of the sediment background approach alone is not sufficient for formulation of toxicity-based sediment quality guideline values, but this approach can provide some critical information in the process of formulating site-specific sediment quality guidelines. The Great Lakes example is the only documented use of this approach.

Spiked-Sediment Toxicity (SST) Approach

This approach to generating sediment quality guidelines relies on empirically generated information on the responses of test organisms to specific contaminant challenges under laboratory conditions. In this procedure, sediments are spiked with known concentrations of contaminants to establish clear cause/effect relationships between chemicals and adverse biological responses (e.g., mortality, reductions in growth or reproduction, physiological changes). Chemicals can be tested alone or in combination to determine the effects of various concentrations of contaminants in sediment. However, information from these types of studies is just beginning to be generated (U.S.EPA 1989a).

Bioassays may also be conducted using unspiked sediments from areas that receive inputs of environmental contaminants, in conjunction with chemical analyses of contaminant concentrations and suitable control tests, to identify those sites that have unacceptable sediment characteristics. Comparison of *in situ* contaminant levels with the results of spiked-sediment bioassays provides a means of identifying priority pollutants in sediments from coastal ecosystems.

The major advantage of this method is its suitability for all classes of chemicals and most types of sediments. In addition, it has the capability to generate precise data on the biological effects of various exposures to toxic chemicals.

The major disadvantage of this method is the projected high costs for its implementation as a regulatory tool. Implementation of this method at a specific site requires collection of data on *in situ* sediment chemistry, on the chemistry of contaminant-spiked sediments, and on the responses of test organisms. The U.S. EPA (1989a) estimated that the cost of generating the chemical and toxicological data necessary to establish a single sediment quality criterion using this method would be in the order of $100 000. In addition, the spiking procedures that are essential for application of this approach are only now in the process of being standardized by the Sediment Toxicology Subcommittee of the American Society for Testing and Materials (ASTM). Also, because the guidelines would be generated in controlled laboratory

experiments, field validation would be required for the sediment criteria generated by this approach. Field validation of this procedure must address the effects of contaminant interactions and the effects of physical sediment variables on the responses of benthic organisms (U.S. EPA 1989a).

This approach has been used for various types of sediments, generally for single contaminants or relatively simple mixtures of contaminants (McLeese and Metcalfe 1980; Cairns et al. 1984; Swartz et al. 1986, 1988, 1989). No data are currently available on the results of field tests that consider various types of sediments with complex mixtures of chemicals.

Water Quality Guidelines (WQG) Approach

In the water quality guidelines approach, sediment quality guidelines are generated from water quality guidelines that have been developed for marine waters. The underlying assumption is that the quality of marine sediments can be assessed by measuring the concentrations of contaminants in the sediment interstitial (pore) water and comparing these concentrations with the marine water quality guidelines (U.S. EPA 1989a). If the interstitial water concentration for a given contaminant exceeds its respective water quality criterion, then the sediment would be expected to cause adverse effects.

The major advantage of this approach is that it is based on the substantial toxicological data bases that have been developed for specific contaminants in marine waters. This feature provides a biological basis for the guidelines, but it assumes similar sensitivities of the water column biota (for which the water quality guidelines were developed) and the benthic infaunal species (which require protection). Only field measurements of contaminant concentrations in the interstitial waters of marine sediments are needed to apply this method.

One of the main disadvantages of this approach is the assumption that the interstitial water is the only route for the exposure of aquatic organisms (specifically benthic infauna) to contaminants. Therefore, other possibilities for significant exposures are neglected, such as dermal exposures through direct contact with the sediments and oral exposures through ingestion of contaminated sediments or food organisms. Other disadvantages of this approach include the lack of standard methods for measuring interstitial water quality and the uncertainty about changes in pore water chemistry after collection and extraction. In addition, water quality guidelines may not be available for many of the potential contaminants of interest, and information on the toxicity of mixtures of contaminants is generally lacking.

Interstitial Water Toxicity (IWT) Approach

The interstitial water toxicity approach is based on a method that is very similar to the water quality guidelines approach described above. The major difference is that an additional assessment is carried out on the potential toxicity of the sediments.

The interstitial water toxicity approach is a multiphase procedure for assessing sediment toxicity using the interstitial (pore) water. The use of pore water for sediment toxicity assessment is based on strong correlations determined between contaminant concentrations in pore water and the toxicity to, and/or bioaccumulation in, benthic macroinvertebrates (U.S. EPA 1989a,1989b). The interstitial water toxicity approach combines an assessment of pore water toxicity with toxicity identification/evaluation (TIE) procedures. In this way, it is possible to identify and quantify the chemical components that are responsible for the toxicity in the sediments. The interstitial water toxicity method involves three major steps:

(1) isolation of pore water from sediment samples;

(2) performance of toxicity tests using pore water; and

(3) application of TIE procedures to pore water fractions.

The initial step in the TIE process is to separate the toxic components of the pore water sample from the non-toxic components. Isolation of the toxic fraction involves a series of sample manipulations and subsequent fractionation techniques in combination with toxicity tests (toxicity tracking).

The advantages of this method are that it involves only routine chemical analyses of the pore water and that most of the toxicity tests are already well established (Michigan State University 1988; Mount 1988; Mount and Anderson-Carnahan 1988a, 1988b).

A major disadvantage of this approach involves obtaining the interstitial water. The interstitial water extracted may not be representative of the actual bioavailability of chemicals to benthic organisms because of chemical/sediment interactions. Other disadvantages of this approach lie in its complexity.

Depending on the nature and number of contaminants present in a sample, this method could become very expensive (i.e., up to $100 000 per substance). Available data show that correlations exist between concentrations of certain contaminants in pore water and their toxicity and/or bioaccumulation (U.S. EPA 1989a), but this relationship may not hold true for other types of contaminants. In addition, when multiple toxicants are present, it may not be possible to determine the proportion of the overall toxicity attributable to each individual contaminant.

This method is relatively new, and, as such, there are no data available on the field validation of the approach or on the applicability of the method for deriving sediment quality guidelines (U.S. EPA 1989a). However, this approach has been used for the assessment of the toxicity of bottom sediments in a single location with good results (Giesy and Hoke 1989). The outlook for this approach is promising if appropriate research continues to support its development.

Equilibrium Partitioning (EP) Approach

The water/sediment equilibrium partitioning approach has been one of the most studied and evaluated approaches used to develop sediment quality guidelines in the United States (Pavlou and Weston 1983; Bolton et al. 1985; Kadeg et al. 1986; Pavlou 1987). The equilibrium partitioning approach is based on the assumptions that the distribution of contaminants among different compartments in the sediment matrix (i.e., sediment solids and interstitial water) is predictable based on their physical and chemical properties and that continuous equilibrium exchange between sediment and interstitial water occurs. This approach also assumes that the interstitial water is the primary route of organism exposure to toxic chemicals.

As in the water quality guidelines approach, water quality guidelines developed for marine ecosystems are used as the basis for the sediment quality guidelines derivation process. Guidelines formulated for the protection of water column species are assumed to be applicable to benthic organisms. Sediment quality guidelines are calculated using the appropriate water quality guidelines in conjunction with the sediment/water partition coefficients for the specific contaminants. This calculation also considers the variability in the estimate of the partition coefficient of the contaminant (i.e., mean and the 95% confidence interval). The calculation procedure for non-ionic organic contaminants is as follows:

$$SQG = K_p \cdot WQG$$

where:

SQG = sediment quality guideline (in $\mu g \cdot kg^{-1}$)

K_p = partition coefficient for the chemical (in $L \cdot kg^{-1}$)

WQG = water quality guideline

The results of bulk chemical analyses may be compared directly with the sediment quality guidelines, or the concentration of various chemicals in the interstitial water may be estimated using the established partition coefficients. In turn, these calculated concentrations in water may be compared with existing marine water quality guidelines for specific chemicals. If the calculated interstitial water concentration for a given contaminant exceeds its respective water quality guideline, then the sediment would be expected to cause adverse effects.

The processes that govern the partitioning of chemical contaminants among sediment, interstitial water, and biota are better understood for some types of chemicals than for others. For some contaminants (e.g., non-polar organic substances), concentrations in the interstitial water are known to be dependent on concentrations in the sediment phase. Sediment total organic carbon (TOC) content appears to be a major factor controlling the partitioning of this class of compounds. For this reason, TOC normalization of contaminant concentrations provides a means of developing sediment quality guidelines applicable to a wide variety of sediment types.

Whereas TOC normalization provides a means of rationalizing data on non-polar organic substances, significant confusion has surrounded the interpretation of data on the concentrations of metals in marine sediments. The standard procedure of normalizing sediment contaminant concentrations to dry weight has not been validated by field or laboratory studies. However, Di Toro et al. (1990) recently demonstrated that the toxicity of cadmium in sediments is directly related to the level of acid volatile sulphide (AVS) in the sediment phase. Adverse effects on benthic invertebrates were observed when the ratio of cadmium to AVS (both expressed in $\mu mol \cdot g^{-1}$) in the sediment exceeded 1. This relationship is expected to apply to all divalent metals. Therefore, AVS appears to provide a means of normalizing levels of sediment metals and could lead to a reliable method for the development of sediment quality guidelines.

The equilibrium partitioning approach has a number of advantages that make it attractive for the derivation of sediment quality guidelines. First, its reliance on information that is generally available (i.e., water quality guidelines, partition coefficients, and bulk sediment chemistry data) makes the approach applicable to a wide variety of aquatic ecosystems. In addition, the equilibrium partitioning theory is well developed, and ongoing field validation is greatly increasing confidence in the approach. Further, the sediment quality guidelines generated using the approach have been used in a variety of regulatory and remedial action applications, and U.S. EPA personnel are confident that the approach will withstand impending court challenges.

The major limitations of this approach are similar to those reported for the water quality guidelines approach. An additional limitation involves the indirect measurement of the quality of the interstitial water; that is, the contaminant concentrations are calculated using bulk sediment chemistry data in conjunction with appropriate partition coefficients. This assumes that the sediment and interstitial water are at equilibrium, which may not be true in many situations. Along with these severe limitations, the U.S. EPA (1989a) identified several others, including the following:

(1) Sediment quality guidelines developed using this approach do not address possible synergistic, antagonistic, or additive effects of contaminants.

(2) Interim sediment quality guidelines currently exist in the United States for only 12 contaminants.

(3) The technical approach for developing sediment quality guidelines for metals is still under development (the AVS methodology is expected to be submitted to the Science Advisory Board for review in 1991; C. Zarba, U.S. EPA, Washington, D.C., pers. com.).

(4) Interim sediment quality guidelines for non-ionic chemicals apply only to sediments that have a significant organic carbon content ($\geq$ 0.5%).

This method has been used primarily in the United States. However, specific regulatory protocols for this approach have not yet been established. A formalized framework for the application of sediment quality guidelines is not expected until the U.S. EPA's Science Advisory Board completes its detailed review of the procedure, scheduled for mid-1991 (C. Zarba, U.S. EPA, Washington, D.C., pers. com). Notwithstanding the lack of a formal protocol, the interim sediment quality guidelines have been used in a pilot study involving six Superfund sites. Unfortunately, the detailed results of field applications are not available because of litigation regarding the cleanup of these sites. At these sites, guidelines have been used to identify the extent of contamination, to assess the risks to human health and the environment, and to identify the environmental benefits associated with a variety of options for remedial action. Field validation of this method (i.e., comparison with biological effects-based methods) is currently under way in Puget Sound, Wash. (U.S. EPA 1989a).

Tissue Residue (TR) Approach

The tissue residue approach (also known as the biota/water/sediment equilibrium partitioning approach) involves the establishment of safe sediment concentrations for individual chemicals or classes of chemicals by determining the sediment chemical concentration that will result in acceptable tissue residues. This two-step process necessitates the quantification of both water/biota and biota/sediment partitioning processes. In addition, relationships must be established between contaminant residues in aquatic biota and adverse effects in consumers of these species.

The tissue residue approach has been used extensively to generate water quality guidelines in the United States (U.S. EPA 1989a). This approach is most applicable to non-polar organic and organometallic compounds that tend to bioaccumulate, that are slowly metabolized, and that may have adverse effects on human health (U.S. EPA 1989a).

The chief disadvantage of this approach, apart from those cited for the equilibrium partitioning approach, is the assumption that the primary route of fish exposure is through the water rather than the food chain. This assumption is known to be false for many persistent toxic substances that bioaccumulate. Another limitation of this method is that the available information on adverse effects of contaminant residues in aquatic biota has not been assembled in a single data base. This could be due to the fact that this method is still in the developmental stage. Further, the field of aquatic toxicology has only recently begun to focus on residue-based, dose/response relationships for contaminants in sediments.

This approach has been used to generate sediment quality guidelines for the protection of aquatic life and wildlife with respect to the aquatic food chain. Sediment concentration limits for 2,3,7, 8-tetrachlorodibenzo-p-dioxin have been established for Lake Ontario on the basis of fish tissue residues (Endicott et al. 1989; Cook et al. 1989). Declines in DDT residues in fish and birds since its use was banned are correlated with declining surficial sediment concentrations in the Great Lakes and the Southern California Bight. The studies cited above support the residue approach for single chemicals, but the use of this approach has not been validated for complex mixtures of chemicals in sediment in order that safe sediment concentrations may be predicted with ecosystem protection in mind (U.S. EPA 1989a).

Benthic Community Structure Assessment (BCSA) Approach

Assessment of benthic community structure is an *in situ* method to assess the quality of bottom sediments that may be used alone, as a component of other approaches (described in following sections), or in combination with other approaches (e.g., the sediment background approach). This assessment technique is not directly applicable to the development of sediment quality guidelines. Rather, it is used to assess impacts on benthic communities that may be related to sediment quality. Specifically, benthic community structure assessments are used to compare test and reference stations in order to determine the existence and magnitude of effects on infaunal species, and to identify spatial and temporal trends in sediment quality.

For practical reasons, assessments of community structure in soft sediments are usually based on data collected on benthic macroinvertebrates (i.e., organisms retained on 1.0- or 0.5-mm sieves). As these species are generally sedentary, benthic community structure is thought to reflect the chemical and physical environment at the sampling location. If this assumption is true, then it follows that benthic community structure may be altered in a predictable manner over time and space by chemical or physical disturbances. Detection of alterations in community structure is dependent on the availability of appropriate sample collection and analytical methods that can be used to distinguish trends in environmental quality from natural variability.

The advantages of this assessment technique are that it is a recognized *in situ* method for determining sediment quality and it can be applied to a wide variety of aquatic ecosystems and a wide variety of contaminant groups.

The disadvantages of this technique are associated with the time and resources that are required to generate and analyze the necessary data. In addition, the information gained is often not suitable for specific management decisions because it does not support the development of numerical guidelines and because it is not possible to identify the specific chemicals responsible for an impact.

This technique has been used extensively to assess the impacts associated with sediments contaminated with trace metals, metalloids, and organic compounds, with dredging and construction-related activities, and with the discharge of mining effluent into the aquatic environment. Various statistical methods (i.e., uni-variate and multi-variate) have been evaluated and employed with this technique to interpret the resultant data (U.S. EPA 1989a).

Screening Level Concentration (SLC) Approach

The screening level concentration approach (Neff et al. 1986) is a biological effects-based approach that is applicable to the development of sediment quality guidelines designed to protect benthic organisms. This approach (Fig. 5) uses data collected in the field on the co-occurrence in sediments of specific benthic biota and various concentrations of environmental contaminants. The screening level concentration (SLC) is an estimate of the highest concentration of a contaminant that can be tolerated (species have to reproduce with no cellular or individual mutations taking place) by a pre-defined proportion (this is an arbitrary number) of the benthic infaunal species.

The SLC is determined through the use of a data base that contains information on the concentration of specific contaminants in sediments and on the occurrence of benthic organisms in the same sediments. First, for each benthic organism for which adequate data are available, a species screening level concentration (SSLC) is calculated. The SSLC is determined by plotting the frequency distribution of the contaminant concentrations over all of the sites in which the species occurs (information from at least 10 sites is required to calculate a SSLC). The 90th percentile of this distribution is taken as the SSLC for the species being investigated. The SSLCs for all of the species for which adequate data are available are compiled as a frequency distribution to determine the concentration that 95% of all the species can tolerate

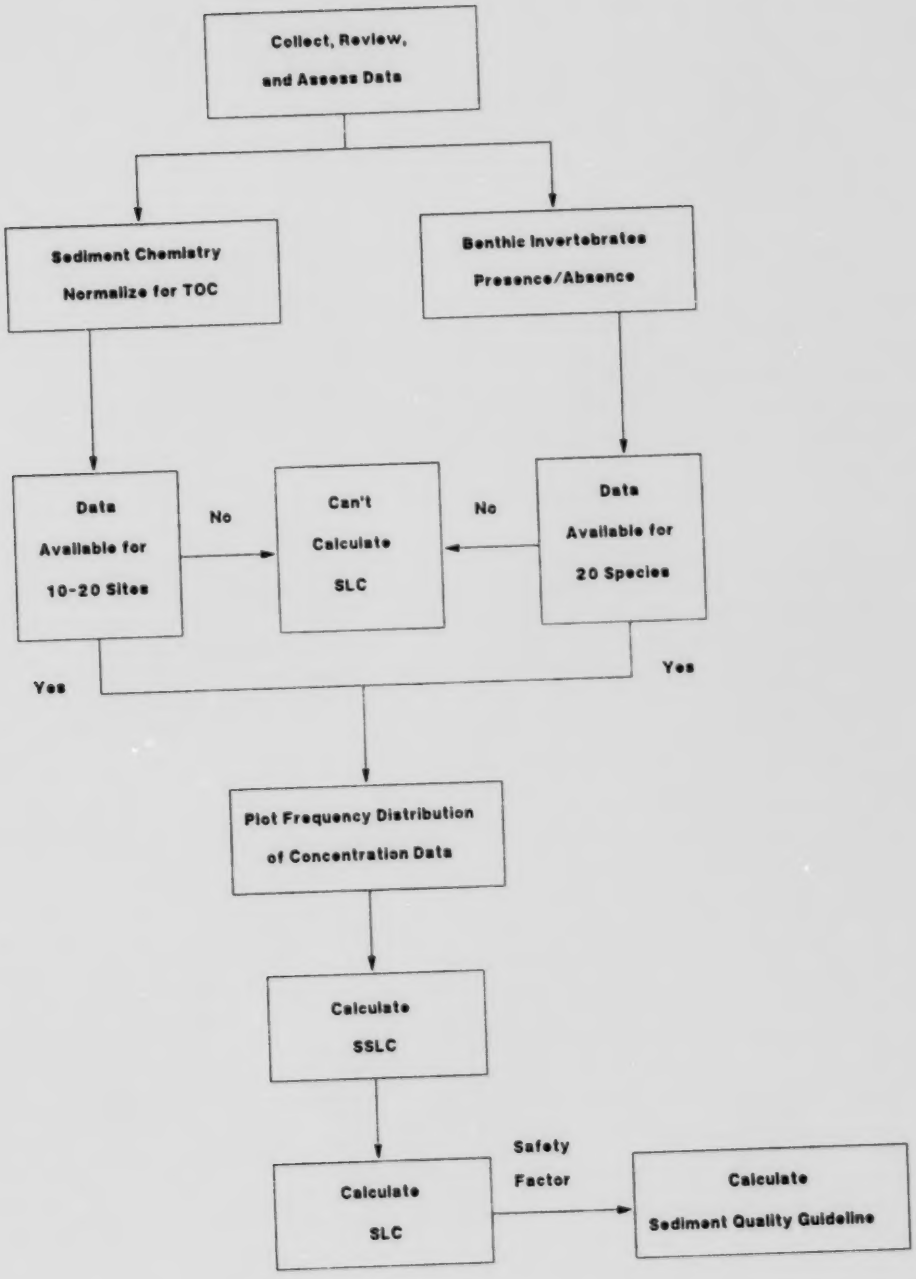

Figure 5. Screening level concentration (SLC) approach.

(i.e., the 5th percentile of the distribution). This concentration is termed the SLC of the contaminant.

The applicability of this approach is improved by normalizing the concentrations of non-polar organic contaminants to the TOC content of the sediments. For metals and polar organic chemicals, bulk sediment concentrations are used, because normalization procedures for these contaminants have not yet been generally accepted.

The advantages of the screening level concentration approach include its versatility and reliance on information that is generally available. It can be used to develop guidelines for virtually any contaminant for which analytical methods are currently available. Further, the SLCs are developed based on specific effects on a variety of organisms that are resident in marine environments. Therefore, the SLCs can be adapted to local conditions by using only a subset of the available data (i.e., data available on the resident species).

The screening level concentration approach relies heavily on a number of assumptions that are implicit in the process. First, this approach assumes that the distribution of benthic organisms is related primarily to the levels of the contaminant of interest in the sediments. The effects of other factors, such as other contaminants, habitat composition (e.g., grain size, water current velocity), and interspecific interactions, are not considered explicitly. However, some of these may be accounted for in the data analysis. Second, the approach assumes that adverse biological effects of a contaminant are manifested only when the species is absent from a particular site. Information on dose/response relationships, which may be assembled using data on population levels or sublethal effects, are largely ignored. Lastly, the screening level concentration approach assumes that the available data base includes concentrations of the contaminant over the full range of tolerance of the species.

Another major limitation of the screening level concentration approach is the difficulty in determining a direct cause/effect relationship between any one contaminant and the benthic biota. As single contaminants are rarely present in field situations, observed effects (i.e., presence or absence of biota) are almost always dependent on the entire mixture of chemicals. In addition, sampling procedures may selectively bias the results of the analysis (e.g., dredge sampling may miss some of the more mobile species). Other disadvantages of the screening level concentration approach are related primarily to the magnitude of its information requirements and reliance on assumptions that may be false or unverifiable. Calculation of an SLC requires information on contaminant concentrations in sediments from at least 10 sites (some scientists suggest that 20 is more appropriate; Chapman 1989) and on the distribution of at least 20 species collected simultaneously. For many contaminants, these data may not be available. Therefore, development of sediment quality guidelines could require the design and implementation of a potentially costly data collection program.

The SLC calculated for a particular contaminant is highly dependent on the quality and quantity of data available. Assessment of the data base is difficult without *a priori* information on the sensitivities of affected species. Therefore, it is difficult to determine how much confidence can be placed on the resultant SLC. Although this approach can be routinely used to develop SLCs, it is virtually impossible to determine the level of protection afforded by these sediment quality guidelines to all benthic organisms in marine, near-shore, and estuarine ecosystems.

Sediment Quality Triad (SQT) Approach

The sediment quality triad approach (Chapman 1986; Fig. 6) to the development of sediment quality guidelines is based on correspondences between three measures: sediment chemistry, sediment bioassays, and *in situ* biological effects. Data on sediment and other (physical) characteristics are collected to assess the level of contamination at a particular site and to document other factors that could influence the distribution and abundance of infaunal species. The results of sediment bioassays provide information on the toxicity of various contaminants in isolation and/or in combination. Measures of *in situ* biological effects, such as benthic infaunal community structure and histopathological abnormalities in bottom fish species, provide information on alterations of resident communities that may be related to sediment chemistry. Integration of these three components provides comprehensive information that may be used to formulate sediment quality guidelines.

The major advantage of the sediment quality triad approach is that it integrates the data generated from the three separate measurements and thereby facilitates the differentiation of natural variability in biotic characteristics from the variability due to the toxic effects of environmental contaminants. That is, variability in measurements of, for example, benthic community composition may be due to the presence of contaminants in sediments or may be related to differences in other aspects of habitat quality (e.g., grain

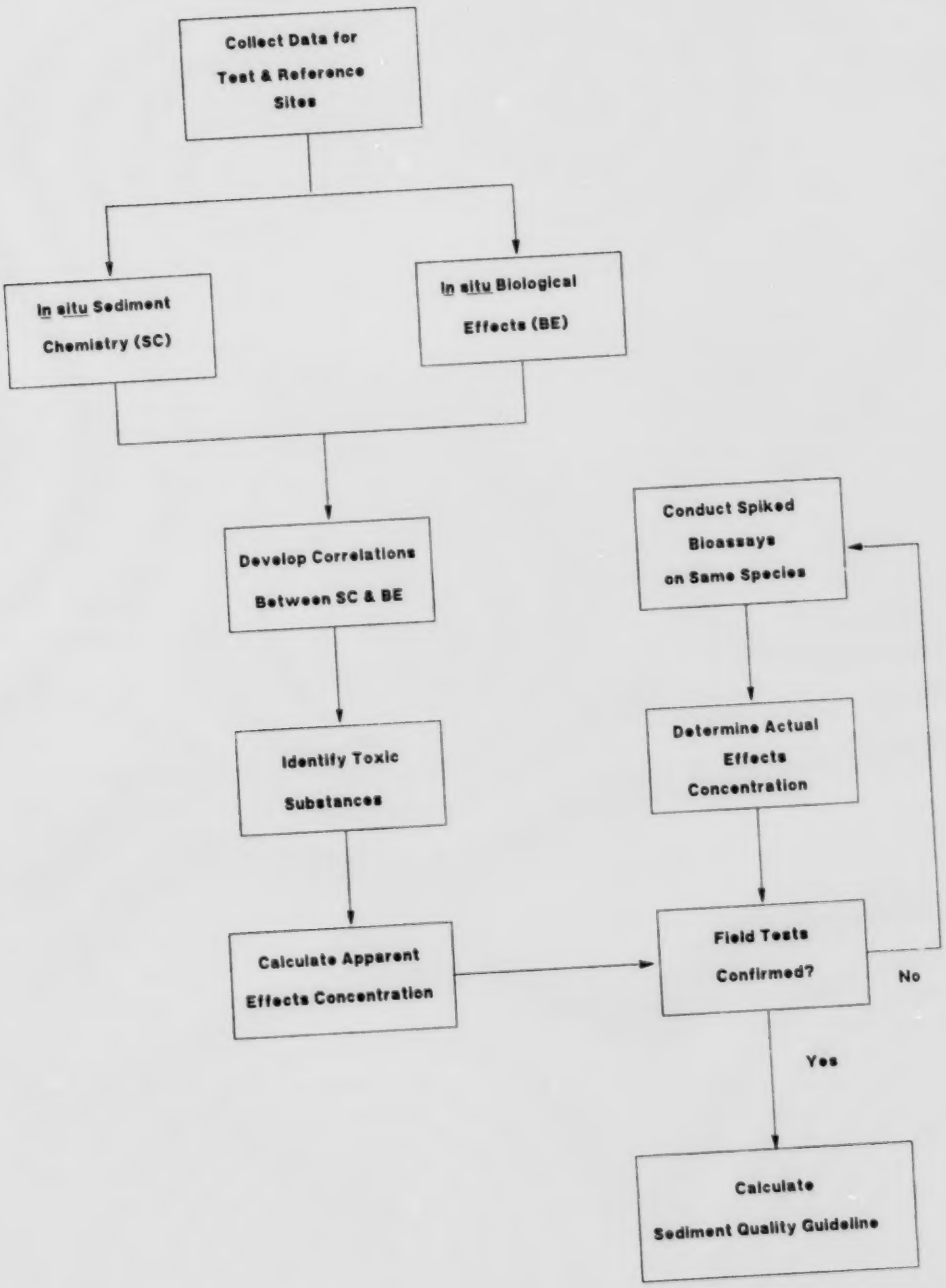
Collect Data for Test & Reference Sites
In situ Sediment Chemistry (SC)
In situ Biological Effects (BE)
Develop Correlations Between SC & BE
Identify Toxic Substances
Calculate Apparent Effects Concentration
Conduct Spiked Bioassays on Same Species
Determine Actual Effects Concentration
Field Tests Confirmed?
No
Yes
Calculate Sediment Quality Guideline

Figure 6. Sediment quality triad (SQT) approach.

size). The sediment quality triad approach provides a basis for distinguishing these effects. The other advantages of this approach are that it can be used for any measured contaminant, it includes both acute and chronic effects, and it does not require information on the specific mechanisms of interaction between organisms and toxic contaminants. The integration of the various types of data provides a weight-of-evidence approach to guidelines development.

The major disadvantages of the sediment quality triad approach are as follows (Chapman 1989):

(1) Statistical criteria have not been developed for use with the triad.

(2) Rigorous criteria for determining single indices for each of the separate measurements have not been developed.

(3) A large data base is required.

(4) It is generally used to develop guidelines for single chemicals; as such, the results can be strongly influenced by the presence of unmeasured toxic contaminants that may or may not co-vary with the measured chemicals.

(5) The methods used in the field of sediment bioassay testing have not yet been standardized and verified with Canadian species.

(6) Sample collection, analysis, and interpretation are labour-intensive and costly.

(7) The choice of a reference site is often made without adequate information on how degraded the site may be.

The sediment quality triad approach has been used primarily in Puget Sound, but it has also been used on the Great Lakes, in Vancouver Harbour, and in San Francisco Bay. In these applications, the sediment quality triad approach has been used to identify priority areas for remedial action, to determine the size of the areas that require remedial action, to verify the quality of reference sites, to determine contaminant concentrations that are always associated with effects on aquatic biota, and to describe ecological relationships between the characteristics of bottom sediments and biota that may be at risk (U.S. EPA 1989a). The sediment quality triad approach has also been tested in the Gulf of Mexico (Chapman et al. 1991) and is currently being used in Europe, specifically the North Sea (P. Chapman, E.V.S. Consultants, North Vancouver, B.C., pers. com.).

Apparent Effects Threshold (AET) Approach

The apparent effects threshold approach (Fig. 7) to the development of sediment quality guidelines was developed by Tetra Tech, Inc. (1986) for use in the Puget Sound area of Washington. The apparent effects threshold approach is based on relationships between measured concentrations of a contaminant in sediments and observed biological effects, mainly on benthic organisms. The practical goal of this procedure is to define the concentration of a contaminant in sediment at which significant biological effects are *always* observed. These biological effects include, but are not limited to, acute and/or chronic toxicity (as measured using sediment bioassays), histopathological changes, changes in the diversity and abundance of various species, and changes in community structure.

The apparent effects threshold approach is similar in many ways to the screening level concentration approach discussed previously. However, the apparent effects threshold approach may be more appropriate than the screening level concentration approach for the development of site-specific sediment quality guidelines, because the apparent effects threshold approach considers diverse and sensitive biological effects. In general, the apparent effects threshold (AET) is based on dry-weight normalized concentrations for metals and TOC normalized concentrations for non-ionic organic contaminants.

The principal advantages of the apparent effects threshold approach relate to its direct use of information on biological effects. It is flexible from the standpoint that both field observations of biological effects and the results of laboratory (spiked or unspiked) bioassays can be used to calculate the AET. Like the screening level concentration approach, it can be used to develop guidelines for virtually any contaminant for which analytical methods are currently available. Unlike the equilibrium partitioning approach, the data base that forms the basis of the AET calculation generally includes data for complex mixtures of contaminants. The resultant AETs are therefore likely to be applicable to a broader range of sites. Further, the AETs may be developed using information on specific effects on a variety of organisms that are resident in the marine environment. Therefore, the AETs can be

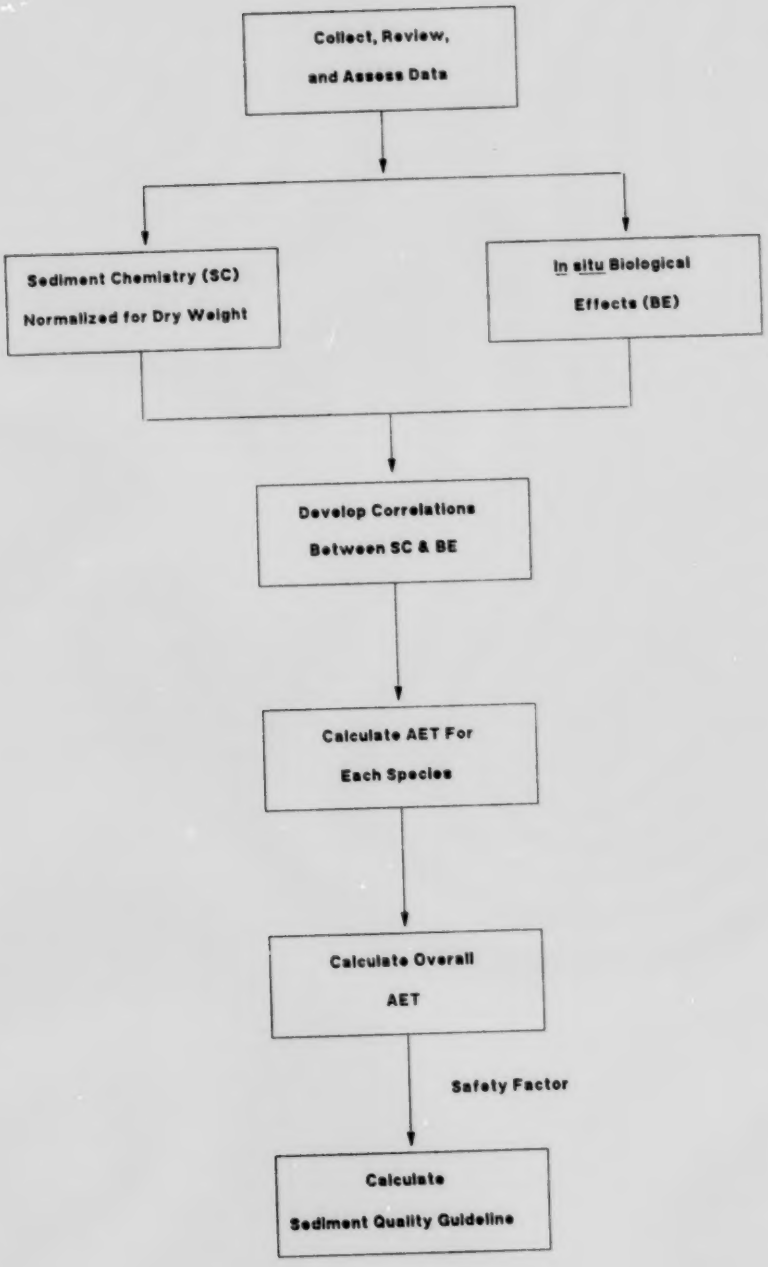

Figure 7. Apparent effects threshold (AET) approach.

adapted to local conditions by considering detailed data on chronic and sublethal effects on sensitive resident species, when these data exist.

The major disadvantage of the apparent effects threshold approach is that there is a substantial risk of under-protection of biological resources if the AET is used directly as the sediment quality guideline. The principal reason for this is that the AET defines the concentration of a contaminant at which biological effects are always observed, and thus it is biased towards the least sensitive species and end points used in the data analysis. Unlike the other approaches to the development of sediment quality guidelines, AETs are likely to *increase* as the data base is expanded to include a more diverse array of end points and species. For example, if a no-observed-effect level (NOEL) in an acute toxicity test with a relatively resistant species were included in the data base, then data indicating chronic toxicity to more sensitive species at the same concentration would be obscured. Thus, where mixed species or end points are used in the calculation of the overall AET, the least sensitive of these will always predominate. The resultant guidelines are not likely to protect the more sensitive species. This limitation may be avoided by defining AET for each species tested and using data for the most sensitive species to develop the guidelines.

For AETs to have real ecological significance, they should be based on chronic and sublethal effects of contaminant exposures. Unfortunately, a comprehensive data base on these end points for a large number of species does not currently exist for most contaminants. In the absence of these data, AETs must be based on acute toxicity data or other specific effects measured in the field or laboratory. Therefore, to adequately protect biological resources in estuarine, coastal, and marine areas, safety factors must be applied to AETs to define sediment quality guidelines.

Another disadvantage of the apparent effects threshold approach is its reliance on monitoring results that could be influenced by factors other than the concentration of the contaminant of interest, such as the presence of other contaminants. For these reasons, the Sediment Criteria Subcommittee of the Science Advisory Board (U.S. EPA 1989c) recommended that the apparent effects threshold approach not be used to develop broadly applicable sediment quality guidelines. It may, however, be appropriate for the derivation of site-specific sediment quality guidelines.

This approach has been used extensively in Washington State by the Puget Sound Dredged Disposal Analysis Program for the evaluation of sediments that were to be dredged and disposed of by ocean dumping. In addition, AETs have been used to assess the effects of the disposal of contaminated sediments at dump sites in that area (Puget Sound Dredged Disposal Analysis 1989).

Sediment Assessment Strategy Recommended by the International Joint Commission (IJC)

The IJC's Sediment Subcommittee has developed a sediment assessment strategy based on protocols that emphasize biological monitoring (IJC 1988). The approach is intended for use in comprehensive assessments of areas (e.g., bays, harbours, rivers, and other depositional zones) where sediment contamination and the need for remedial action are suspected. Although the recommended strategy is designed to minimize the costs, these assessments are likely to be relatively large undertakings and, as such, are appropriate for use in situations in which large-scale remedial actions might be contemplated. Nevertheless, some of the components of this strategy could be useful for the derivation of sediment quality guidelines. A fundamental assumption of the strategy is that contaminated sediments are a concern only if they are exerting a stress on biological systems or if toxic substances are being bioaccumulated.

The objectives of the proposed strategy are:

(1) to provide accurate assessments of specific problems by using an approach that integrates chemical, physical, and biological information;

(2) to perform tasks in a sequence so that the results from each technique can be used to reduce subsequent sampling requirements and costs;

(3) to provide adequate evidence of linkages between the contamination and the observed biological impact;

(4) to quantify problem severity, thereby enabling inter- and intra-comparisons of areas being investigated (thus allowing the development of a priority list for remedial actions and the objective selection of appropriate remedial options); and

(5) to consider the effects on different species and different trophic levels, as biological impairment

may occur in the water column as well as the sediments if resuspension occurs.

The IJC approach is an integrated strategy that is designed to provide the data necessary to identify sites with problematic levels of sediment contamination, to document effects, to rank the severity of the problem, and to assist in the selection of remedial options. The major advantage of this method is that it considers (like the sediment quality triad approach) all of the important physical and chemical factors and biological effects with respect to bottom sediments.

The main disadvantages of this approach are that it could be very costly and time-consuming, and the final data interpretation must be carried out by highly trained professionals. This approach has been formulated for use in the Areas of Concern on the Great Lakes and not for generating numerical sediment quality guidelines. However, the process is likely to generate the type and quantity of data that would be required to support the derivation of sediment quality guidelines (M. Zarull, IJC, Windsor, Ont., pers. com.). This approach is now being tested at Great Lakes Areas of Concern under the Assessment and Remediation of Contaminated Sediments (ARCS) under the auspices of the U.S. EPA's Great Lakes National Program Office (Ross 1989).

National Status and Trends Program Data Base (NSTP-DB) Approach

Another possible approach to sediment quality guidelines development is currently being investigated by the National Status and Trends Program (NS&TP, NOAA). Long and Morgan (1990) compiled a data base containing information generated by effects-based approaches—specifically, the equilibrium partitioning approach, the spiked bioassay approach, and various contaminant/biological effect co-occurrence approaches (AET, SLC, SQT). The data base weighted information equally, regardless of the method that was used to develop it. The objective of this assessment was to identify informal guidelines for use in the evaluation of sediment data collected under the NS&TP. The appropriateness of each data set obtained was assessed using a screening procedure that considered the experimental methods that were used, the type and magnitude of the end point measured, and the degree of concordance between the chemical and biological data. Professional judgement was, in many cases, used to distinguish between effects and trends associated with chemical gradients and those associated with habitat gradients. Data that showed no concordance between chemical and biological variables were incorporated into the data base but were not used in the statistical evaluation of the information.

The data that passed the screening tests were incorporated into the data base on a variable-by-variable basis. Individual entries consisted of the concentration of the contaminant, the type of biological response measured (usually specifying the location of the test as well), and an indication of whether or not an effect was observed (i.e., no effect, no or small gradient, no concordance, or a hit, which indicated that an effect was measured). The data were sorted in ascending order of concentration, and statistical analysis was performed to facilitate definition of the 10th and the 50th percentile concentrations for each compound. The effects range–low (ER-L; 10th percentile value) represented a lower threshold value, above which adverse effects on sensitive life stages and/or species begin. The effects range–median (ER-M; 50th percentile value) represented a second threshold value, above which adverse effects on most species are frequently or always observed. These two parameters, ER-L and ER-M, were then used as informal sediment quality guidelines.

The main advantage of this approach is that no additional fieldwork or laboratory investigations are required. However, the compilation and evaluation of the data are very labour-intensive and require sound knowledge of sediment chemistry and biology. The other major benefit of this approach is that all of the available data generated in the United States have been compiled with respect to the various approaches described previously. Canadian and other pertinent data could be added to this data base to increase its applicability. Where appropriate, safety factors could be incorporated into the guidelines development process for further protection of the marine environment. The use of safety factors would be warranted when effects on sensitive species known to occur in Canadian waters are not included in the data base or when considering substances known to bioaccumulate.

The main limitation of this approach is that the data on the contaminant concentrations in sediments and their biological effects have originated from a large number of locations across the United States. For this reason, information on a wide variety of sediment types (e.g., with different particle sizes and different background concentrations of trace and major elements) has been combined, which could result in unknown biases. As well, this amalgamation of the data could result in the interpretation of responses as being attributable to a single contaminant when, in

fact, synergistic and/or additive effects may actually be driving the responses. In addition, inappropriate guidelines could be derived for substances for which only a moderate amount of information exists.

The data base consists of sediment data generated by the NS&TP from over 200 locations around the United States. Long and Morgan (1990) emphasized that the degree of confidence in the ER-L and ER-M values should be considered as moderate for metals and PCBs and low for pesticides and PAHs. They felt that although the compiled data base was fairly extensive, many more data were needed to support or refute this approach for all groups of chemicals, for individual analytes within the groups, and for all types of sediments.

An Approach to the Development of Canadian MEQ Guidelines for Sediment

A compilation of sediment quality guidelines developed using the various approaches and in use by various jurisdictions in North America, Europe, and Japan is presented in Appendix G. Inspection of these sediment quality guidelines reveals that the actual numerical concentrations recommended for various contaminants differ usually by two or more orders of magnitude and in many cases by over three orders of magnitude. It is unlikely that differences in the sensitivities of the aquatic biota tested are responsible for these ranges of guideline values. More likely, much of this variability is related to the limitations associated with the application of the various approaches used in developing these guidelines.

The general lack of agreement among the sediment quality guidelines that have been developed using the various approaches suggests that, whereas each of the approaches may be appropriate for specific applications, no single approach is universally applicable. Therefore, in recommending an approach to the development of Canadian sediment quality guidelines, it is imperative that values obtained from each of the approaches be fully evaluated to assess their applicability to Canadian environmental conditions and environmental management objectives. A summary of the advantages and limitations of each of the approaches to the development of Canadian sediment quality guidelines is provided in the following discussion and in Table 3.

A major shortcoming of the current biological effects-based approaches (SLC, AET, SQT, BCSA) is that none of these takes into account the ultimate fate and effects of highly bioaccumulative contaminants such as DDT and PCBs. For these types of substances, the importance of single-species toxicity data is likely to be eclipsed by data on whole-ecosystem effects, if these latter data were available (Harding 1989). With respect to the sediment quality triad approach, there are no validated statistical methods available for dealing with data on more sensitive biological responses (e.g., histopathology, sublethal effects). The absence of these statistical methods makes it difficult to incorporate these data and, subsequently, to generate sediment quality guidelines using this approach. Also, none of the biological effects-based approaches takes into account the background concentrations of trace elements, and thus they could result in the generation of sediment quality guidelines that are unrealistic under certain conditions.

Another serious drawback of the biological effects-based approaches is the lack of consideration given to the use of safety factors. When using the apparent effects threshold approach, Washington State authorities have applied an arbitrary safety factor of 0.1 (Harding 1989). In Canada, an arbitrary safety factor of 0.01 is used in the ocean dumping program to assess the toxicity of halogenated organic compounds (Ocean Dumping Regulations 1988a). The basis for the use of any of these safety factors should be clearly stated.

Each of the approaches reviewed in this document has one or more serious flaws that limit its utility for developing nationally applicable marine sediment quality guidelines. Therefore, it is not possible to recommend a single approach for adoption by the CCME and the Marine Environmental Quality Program under Environment Canada. It is recommended that the first step in the process involve the definition of the intent and intended use of the sediment quality guidelines. These decisions will greatly influence the derivation procedure that will be used to develop the guidelines (e.g., choice of safety factors, minimum data requirements). A document on the intent and intended use of Canadian sediment quality guidelines is currently available (Environment Canada 1989).

There is a critical need for sediment quality guidelines applicable to marine ecosystems in Canada. These guidelines are required to assess sediment quality issues and concerns (including those associated with the ocean dumping program) and to establish site-specific sediment quality objectives. Therefore, to adequately address this need, a strategic approach to the development of Canadian sediment quality guidelines is recommended.

Table 3. Summary of the Advantages and Limitations of Various Approaches to the Development of Sediment Quality Guidelines

Approach	Advantages	Limitations
Sediment background (SB)	• Only data on bulk sediment chemistry are required.	• No direct biological or toxicological data are used.
Spiked-sediment toxicity (SST)	• Suitable for most classes of chemicals and most types of sediments. • Generates precise biological effects data.	• Implementation costs are likely to be high if used as a regulatory tool. • Spiking procedures are not yet standardized. • Field validation required.
Water quality guidelines (WQG)	• Water quality guidelines are available for many variables, and toxicological data are available for many more chemicals. • Only field measurements of interstitial water needed.	• Assumes major route of exposure of aquatic organisms to contaminants is through interstitial water. • Few data are available on the toxicity of complex mixtures of contaminants. • Assumes similar sensitivities of water column biota and benthic infaunal species.
Interstitial water toxicity (IWT)	• Only routine measurement of chemicals in pore water is necessary, and most of the toxicity tests used are established.	• Implementation costs may be high. • Only limited data are available on the correlations between interstitial water quality and toxicity and/or bioaccumulation. • No standardized methods for measuring interstitial water quality and uncertainty about changes in pore water chemistry after collection and extraction.
Equilibrium partitioning (EP)	• Applicable to a wide variety of aquatic systems. • Requires only existing water quality guidelines and site-specific chemistry data. • The U.S. EPA is supporting research that will provide data for, and field validation of, this method.	• Does not address synergistic, additive, or antagonistic effects of contaminants. • Assumes sediment and interstitial water are at equilibrium. • The chemical concentration in interstitial water is indirectly measured. • Assumes major route of exposure of aquatic organisms to contaminants is through interstitial water. • Technical approach for developing sediment quality criteria for metals is still under way.
Tissue residue (TR)	• Has been used extensively to develop water quality guidelines.	• Assumes that the primary route of exposure is via the water rather than the food chain. • The method is still in the developmental stages.
Benthic community structure assessment (BCSA)	• Has been recognized as a valuable *in situ* method for evaluating sediment quality. • Can be applied over a wide variety of aquatic ecosystems and contaminant groups.	• Time-consuming and expensive. • Specific chemicals responsible for impact not identified.
Screening level concentration (SLC)	• Versatility and reliance on data that are generally available. • Based on specific effects on resident marine organisms.	• Difficult to determine direct cause/effect relationships. • Assumes distribution of benthic organisms is primarily related to sediment chemistry. • Assumes adverse effects manifested only when species absent from site. • Large data base required. • Difficult to determine level of protection afforded to benthic organisms.

Table 3. Continued

Approach	Advantages	Limitations
Sediment quality triad (SQT)	• Integrates data from three separate measurements to help distinguish toxic effects from natural variability. • Can be used for any measured contaminant.	• Difficult to determine guidelines for single chemicals. • Labour-intensive and expensive. • Bias may result from unmeasured contaminants. • Sediment bioassay tests not yet standardized. • Statistical criteria needed.
Apparent effects threshold (AET)	• Uses information on biological effects to develop guidelines. • Can be used for any chemical for which analytical methods are available. • Both field observations and laboratory bioassays can be used.	• Substantial risk of under-protection if AET is used directly as sediment quality guideline. • AETs are likely to increase as the data base is expanded. • AETs are based primarily on acute effects; chronic and sublethal effects have not been considered.
International Joint Commission (IJC)	• Considers all of the important physical and chemical factors and biological effects.	• Costly and time-consuming. • Applicable to areas where remedial action is needed.
National Status and Trends Program Database (NSTP-DB)	• No fieldwork is necessary. • Incorporates information generated from all effects-based approaches. • Required data are readily available.	• Formalized protocols have not yet been developed to generate guidelines from these data. • Labour-intensive. • Data have originated from a large number of locations across the United States and could result in unknown biases.

In the short term, interim sediment quality guidelines should be established using information that is currently available and in use in other jurisdictions. Beak Consultants Ltd. (1988) recommended a three-tiered approach to the selection of sediment quality guidelines for each chemical or group of chemicals (if appropriate data are available), which gives preference to the biological effects-based values. The three-tiered system, which is endorsed for the selection of interim sediment quality guidelines in Canada, is outlined below:

(1) Select the lowest of the effects-based guidelines (AET, SLC, SQT, or NSTP-DB) if any of these have been or can be calculated. (Note that a formal procedure for deriving sediment quality guidelines using the NSTP-DB approach is currently under development.)

(2) For organic contaminants, use the lower value obtained from the equilibrium partitioning and water quality guidelines approaches, if no effects-based guidelines are available. (The new equilibrium partitioning approach may be used to develop sediment quality guidelines for metals if the AVS normalization procedure is approved by the U.S. Science Advisory Board.)

(3) With respect to the development of site-specific objectives, the background limit should be used as the interim sediment quality guideline if the interim guideline formulated from either of the first two tiers is below the upper background limit of trace elements.

The rationale behind these recommendations is that the effects-based approaches are thought to be most ecologically relevant and, therefore, defensible because they rely directly on dose/response data. Guidelines derived using partitioning methods are based only indirectly on biological effects—i.e., only to the extent that the water quality guidelines used are effects-based. Sediment quality guidelines developed using the sediment background approach are not based on biological effects at all.

In the longer term, as the sediment toxicity literature expands, a formalized protocol should be developed to derive guidelines from information on specific responses to contaminant challenges. Such a protocol should specify minimum data requirements (toxicity and environmental fate), data assessment criteria, appropriate safety factors, and other factors relevant to the guidelines derivation procedure.

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Appendix A
A Compilation of Water Quality Guidelines for the Protection of Aquatic Life: General Variables

Table A-1. A Compilation of Water Quality Guidelines for the Protection of Aquatic Life: General Variables

Variable	Value	Approach	Rationale	Jurisdiction	Reference
Aesthetic considerations	Narrative	WB	Waters should be: a) free from substances that will settle to form putrescent or otherwise objectionable sludge deposits; b) free from floating debris, oil, grease, scum, foam, and other floating materials in amounts sufficient to be unsightly or otherwise objectionable; c) free from materials that will produce colour, odour, turbidity, or other conditions to such a degree as to be unsightly or otherwise objectionable; Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
Barriers	Narrative	WB	No barrier should be constructed, substances added, or alterations made to the marine or estuarine environment that will prevent the normal movement and migratory patterns of fish and other aquatic organisms to the detriment of their populations or cause changes in the normal water movement pattern that will lead to adverse effects upon them; Class 2 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
Chemical oxygen demand	2 $mg \cdot L^{-1}$		Maximum; protection of aquatic life such as red sea-bream, yellow tail, and seaweed and conservation of other natural resources	Japan	Japan Environment Agency 1987
	3 $mg \cdot L^{-1}$		Maximum; protection of aquatic life such as gray mullet, laver, etc.	Japan	Japan Environment Agency 1987
Coliforms, total	70 MPN/100 mL		Maximum; median or geometric mean; approved growing area for the harvesting of shellfish (oysters, mussels, clams)	United States	National Shellfish Sanitation Program 1990
	70 MPN/100 mL		Maximum concentration; median; at all areas where shellfish are harvested	California	California State Water Resources Control Board 1989
	230 MPN/100 mL		Maximum; 90th percentile; approved growing area for the harvesting of shellfish (oysters, mussels, clams)	United States	National Shellfish Sanitation Program 1990
	230 MPN/100 mL		Maximum; 90th percentile; at all areas where shellfish are harvested	California	California State Water Resources Control Board 1989
	1000 MPN/100 mL		Maximum total number of groups; protection of aquatic life such as red sea-bream, yellow tail, seaweed, gray mullet, laver, etc., and conservation of other natural resources	Japan	Japan Environment Agency 1987
Colour	50 units		Applies to shellfish areas	British Columbia	Pommen 1989
	50 units	WB	Maximum reduction for waters with no established norm; colour or apparent colour shall not reduce the depth of compensation point for photosynthetic activity	Alaska	Alaska Department of Environmental Quality 1989
	50 units		Water supply for aquaculture	Alaska	Alaska Department of Environmental Quality 1989

MPN = mean probable number
NTU = nephelometric turbidity unit
TT = theoretical toxicological
WB = water background

Table A-1. Continued

Variable	Value	Approach	Rationale	Jurisdiction	Reference
Colour	10%	WB	Maximum reduction from seasonally established norm; colour or apparent colour shall not reduce the depth of compensation point for photosynthetic activity	Alaska	Alaska Department of Environmental Quality 1989
	Narrative	WB	Waste discharge shall not cause aesthetically undesirable discolouration	California	California State Water Resources Control Board 1989
	Narrative	WB	Turbidity should not reduce the depth of the compensation point for photosynthetic activity by more than 10% from the seasonally established norm	United States	U.S. EPA 1987
Dissolved gas, total	110%		Maximum; shall not exceed this percent saturation value at any point of sample collection; Classes AA, A, and B (2)	Washington	Washington State 1988
	110%	WB	Maximum; shall not exceed this percent saturation value at any point of sample collection; water supply for aquaculture	Alaska	Alaska Department of Environmental Quality 1989
	110%		Maximum percent saturation; to protect aquatic life; at existing atmospheric and hydrostatic pressures	United States	U.S. EPA 1987
Dissolved oxygen (DO)	0.2 $mg \cdot L^{-1}$	WB	Maximum change from natural conditions, due to human activities	Washington	Washington State 1988
	2.0 $mg \cdot L^{-1}$		Minimum; conservation of environment	Japan	Japan Environment Agency 1987
	4.0 $mg \cdot L^{-1}$		Minimum; below 1 m; in coastal water, except when natural conditions cause this value to be depressed	Alaska	Alaska Department of Environmental Quality 1989
	4.0 $mg \cdot L^{-1}$		Minimum; Class C (2)	Washington	Washington State 1988
	4.3 $mg \cdot L^{-1}$		Minimum; Class 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	5.0 $mg \cdot L^{-1}$		Minimum; Class B (2)	Washington	Washington State 1988
	5.0 $mg \cdot L^{-1}$		Minimum for up to 6 h; Class 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	5.0 $mg \cdot L^{-1}$		Minimum; Class 2 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	5.0 $mg \cdot L^{-1}$		Minimum; in estuaries and tidal tributaries	Alaska	Alaska Department of Environmental Quality 1989
	5.0 $mg \cdot L^{-1}$		Minimum; protection of Class 2 fisheries	Japan	Japan Environment Agency 1987
	5.7 $mg \cdot L^{-1}$		Minimum for up to 6 h; Class 2 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981

Table A-1. Continued

Variable	Value	Approach	Rationale	Jurisdiction	Reference
Dissolved oxygen (DO)	6.0 $mg \cdot L^{-1}$		Minimum; Class A (2)	Washington	Washington State 1988
	6.0 $mg \cdot L^{-1}$		Minimum; to depth of 1 m; in coastal water, except when natural conditions cause this value to be depressed	Alaska	Alaska Department of Environmental Quality 1989
	6.0 $mg \cdot L^{-1}$		Minimum; estuarine waters outside of zones of upwelled marine waters naturally deficient in DO (3)	Oregon	Oregon Department of Environmental Quality 1989b
	6.5 $mg \cdot L^{-1}$		Minimum; moderate level of protection; anadromous species, including salmonids	British Columbia	Pommen 1989
	6.5 $mg \cdot L^{-1}$		Minimum; Boundary Bay (4)	British Columbia	Swain and Holms 1988
	6.75 $mg \cdot L^{-1}$		Minimum; moderate level of protection; non-anadromous species	British Columbia	Pommen 1989
	7.0 $mg \cdot L^{-1}$		Minimum; Class AA (2)	Washington	Washington State 1988
	7.5 $mg \cdot L^{-1}$		Minimum; protection of Class 1 fisheries	Japan	Japan Environment Agency 1987
	7.75 $mg \cdot L^{-1}$		Minimum; Fraser River including the Main Stem, North, Middle, and Main arms (4)	British Columbia	Swain and Holms 1985
	7.8 $mg \cdot L^{-1}$		Minimum; Kitimat River downstream from the District of Kitimat sewage discharge (4)	British Columbia	Warrington 1987
	8.75 $mg \cdot L^{-1}$		Minimum; high level of protection; non-anadromous species	British Columbia	Pommen 1989
	9.0 $mg \cdot L^{-1}$		Minimum; high level of protection; anadromous species, including salmonids	British Columbia	Pommen 1989
	9.0 $mg \cdot L^{-1}$		Minimum; Sturgeon and Roberts banks (4)	British Columbia	Swain and Holms 1985
	9.0 $mg \cdot L^{-1}$		Minimum; Boundary Bay; represents a long-term objective (4)	British Columbia	Swain and Holmes 1988
	17 $mg \cdot L^{-1}$		Maximum; to depth of 1 m; in coastal water, except when natural conditions cause this value to be depressed	Alaska	Alaska Department of Environmental Quality 1989
	< saturation concentration		Marine waters; outside of zones of upwelled marine waters naturally deficient in DO (3)	Oregon	Oregon Department of Environmental Quality 1989b
	10%	WB	Maximum reduction from that which occurs naturally, as the result of the discharge of oxygen-demanding waste materials	California	California State Water Resources Control Board 1989
	>70% saturation		Average; mandatory for shellfish waters; monthly sampling; where major daily variations are suspected, a minimum of two samples per day shall be taken	Europe	Commission of the European Communities 1988

Table A-1. Continued

Variable	Value	Approach	Rationale	Jurisdiction	Reference
Fecal coliforms	14 MPN/100 mL		Maximum; geometric mean; human health concerns (oysters, mussels, clams)	Canada	National Shellfish Sanitation Program 1990
	14 MPN/100 mL		Maximum; geometric mean; human health concerns (oysters, mussels, clams)	United States	National Shellfish Sanitation Program 1990
	14 MPN/100 mL		Maximum; geometric mean; Classes AA and A (2)	Washington	Washington State 1988
	43 MPN/100 mL		Maximum; 90th percentile; human health concerns (oysters, mussels, clams)	Canada	National Shellfish Sanitation Program 1990
	43 MPN/100 mL		Maximum; 90th percentile; human health concerns (oysters, mussels, clams)	United States	National Shellfish Sanitation Program 1990
	43 MPN/100 mL		Maximum; 90th percentile; Classes AA and A (2)	Washington	Washington State 1988
	88 MPN/100 mL		Maximum; median or geometric mean; restricted area for controlled purification of shellfish (oysters, mussels, clams)	Canada	National Shellfish Sanitation Program 1990
	88 MPN/100 mL		Maximum, median or geometric mean; restricted area for controlled purification of shellfish (oysters, mussels, clams)	United States	National Shellfish Sanitation Program 1990
	100 MPN/100 mL		Maximum; geometric mean; Class B (2)	Washington	Washington State 1988
	200 MPN/100 mL		Maximum; 90th percentile; Class B (2)	Washington	Washington State 1988
	200 MPN/100 mL		Maximum concentration; log mean; estuarine waters other than shellfish growing waters (3)	Oregon	Oregon Department of Environmental Quality 1989b
	200 MPN/100 mL		maximum geometric mean; Class C (2)	Washington	Washington State 1988
	260 MPN/100 mL		Maximum; 90th percentile; restricted area for controlled purification of shellfish (oysters, mussels, clams)	Canada	National Shellfish Sanitation Program 1990
	260 MPN/100 mL		Maximum; 90th percentile; restricted area for controlled purification of shellfish (oysters, mussels, clams)	United States	National Shellfish Sanitation Program 1990
	300/100 mL		Maximum in flesh and intervalvular fluid or flesh	Mediterranean	World Health Organization 1985
	400 MPN/100 mL		Maximum; 90th percentile; estuarine waters other than shellfish growing waters (3)	Oregon	Oregon Department of Environmental Quality 1989b
	400 MPN/100 mL		Maximum; 90th percentile; Class C (2)	Washington	Washington State 1988
Floating and submerged litter	Narrative	WB	No materials should be present that directly or indirectly have an adverse effect upon aquatic organisms; Class 2 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981

Table A-1. Continued

Variable	Value	Approach	Rationale	Jurisdiction	Reference
General	Narrative	TT	Should any individual species or component of the ecosystem be known to have lower tolerances than those specified for any given criterion, then these levels should be those used in setting water quality objectives; Class 2 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	Ambient levels	WB	Water quality parameters should be maintained at pristine or ambient levels where applicable; waters should not be modified by human activities in any way; based on data from as long a time period as possible and not less than 3 years; Class 1 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
Ionic ratio	Narrative	WB	The ratios of major ions should not be altered such that the beneficial use is affected; Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
Light attenuation	10%	WB	Maximum reduction; the combined effects of turbidity and colour should not reduce the depth of the compensation point for photosynthetic activity from the seasonal background value; Class 2 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	50%	WB	Maximum reduction; the combined effects of turbidity and colour should not reduce the depth of the compensation point for photosynthetic activity from the seasonal background value; Class 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
Oil, grease	Narrative		Surface waters shall be virtually free from floating non-petroleum oils of vegetable or animal origin, as well as petroleum-derived oils	United States	U.S. EPA 1987
	Narrative	TT	Shall not exceed 0.01 times the lowest continuous-flow 96-h LC_{50} to several important marine species, each having demonstrated high susceptibility to oils and petrochemicals	United States	U.S. EPA 1987
	Narrative		Should not be visible	California	California State Water Resources Control Board 1989
	Narrative	TT	Shall not exceed 0.01 times the continuous-flow 96-h LC_{50} or, if not available, the static test 96-h LC_{50} for the species involved; aquaculture	Alaska	Alaska Department of Environmental Quality 1989
pH units	0.2 units	WB	Maximum change from natural levels	California	California State Water Resources Control Board 1989
	6.0–9.0	WB	Class 2 protection, for waters of salinity below 5 ppt, no change in excess of 0.5 units from normal; Class 3 protection, no change in excess of 1.0 unit from normal (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	6.5–8.5			British Columbia	Pommen 1989
	6.5–8.5		Fraser River including the Main Stem, North, Middle, and Main arms (4,5)	British Columbia	Swain and Holms 1985
	6.5–8.5		Estuarine waters (3)	Oregon	Oregon Department of Environmental Quality 1989b

Table A-1. Continued

Variable	Value	Approach	Rationale	Jurisdiction	Reference
pH units	6.5–8.5	WB	Shall not vary more than 0.1 pH unit from natural conditions; variation of pH for waters naturally outside the specified range shall be towards the range	Alaska	Alaska Department of Environmental Quality 1989
	6.5–8.5	WB	Class 2 protection, no change in excess of 0.2 units from normal; Class 3 protection, no change in excess of 0.5 units from normal (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	6.5–9.0		Kitimat River downstream from the District of Kitimat sewage discharge (4)	British Columbia	Warrington 1987
	6.5–9.0	WB	Class C, with a man-caused variation of less than 0.5 units (2)	Washington	Washington State 1988
	7.0–8.3		Conservation of the environment	Japan	Japan Environment Agency 1987
	7.0–8.5		Marine waters (3)	Oregon	Oregon Department of Environmental Quality 1989b
	7.0–8.5	WB	With a man-caused variation of less than 0.2 units for Class AA; less than 0.5 units of variation for Classes A and B (2)	Washington	Washington State 1988
	7.0–9.0		Mandatory for shellfish waters; quarterly sampling	Europe	Commission of the European Communities 1988
	7.8–8.3		Protection of Classes 1 and 2 fisheries	Japan	Japan Environment Agency 1987
Pulp mill effluent	Narrative	TT	The percent concentration should be less than 0.05 of the 96-h LC_{50} of pulp mill effluent; Kitimat River downstream from the District of Kitimat sewage discharge; to protect salmonid resources (4,6)	British Columbia	Warrington 1987
Residues	Narrative		Shall not alone or in combination with other substances or wastes cause: a) the water to be unfit or unsafe for use; b) detrimental effects on established water supply treatment levels; c) a film, sheen, or discoloration on the surface of the water or adjoining shoreline; d) leaching of toxic or deleterious substances; or e) a sludge, solid, or emulsion to be deposited beneath or upon the surface of the water, within the water column, on the bottom, or upon adjoining shorelines; aquaculture, seafood processing, and harvesting of raw molluscs or other aquatic life	Alaska	Alaska Department of Environmental Quality 1989
	Narrative		Floating particulates shall not be visible; the rate of deposition of inert solids and the characteristics of inert solids in ocean sediments shall not be changed such that benthic communities are degraded	California	California State Water Resources Control Board 1989
Salinity	10%	WB	Maximum change; $g \cdot L^{-1}$ NaCl or equivalent; estuarine; 6% maximum for waterfowl marshes; vegetation suffers above this limit	British Columbia	Pommen 1989
	1 $g \cdot L^{-1}$	WB	Maximum 24-h changes for estuarine and marine communities; natural salinity 0–3.5 ppt	British Columbia	Pommen 1989

Table A-L. Continued

Variable	Value	Approach	Rationale	Jurisdiction	Reference
Salinity	2 g·L^{-1}	WB	Maximum 24-h changes for estuarine and marine communities; natural salinity 3.5–13.5 ppt	British Columbia	Pommen 1989
	4 g·L^{-1}	WB	Maximum 24-h changes for estuarine and marine communities; natural salinity 13.5–35 ppt	British Columbia	Pommen 1989
	1 ppt	WB	Man-induced, maximum allowable variation above natural salinity of 0–3.5 ppt	Alaska	Alaska Department of Environmental Quality 1989
	2 ppt	WB	Man-induced, maximum allowable variation above natural salinity of 3.5–13.5 ppt	Alaska	Alaska Department of Environmental Quality 1989
	4 ppt	WB	Man-induced, maximum allowable variation above natural salinity of 13.5–35 ppt	Alaska	Alaska Department of Environmental Quality 1989
	12-38 ppt		Guideline; monthly sampling	Europe	Commission of the European Communities 1988
	<40 ppt	WB	Mandatory; discharge affecting shellfish waters must not cause their salinity to exceed by more than 10% the salinity of waters not so affected	Europe	Commission of the European Communities 1988
	Narrative	WB	Maximum change; unnatural influences should not change the seasonal mean salinity, measured preferably over not less than 5 years, by more than 0.25 standard deviations, nor change the salinity beyond the range recorded over that period; Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
Settleable matter	Narrative	WB	Unnatural inputs of settleable material should not cause the formation of deposits that are harmful to aquatic organisms; Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
Substrate sedimentation	0	WB	No significant increase, 95% confidence limit; for salmonid spawning; particulate matter < 3 mm in diameter	British Columbia	Pommen 1989
	0		For mariculture; particulate matter	British Columbia	Pommen 1989
Suspended solids	10 mg·L^{-1}	WB	Maximum; non-filterable residue; background less than 100 mg·L^{-1}; man-induced	British Columbia	Pommen 1989
	80 mg·L^{-1}	WB	Maximum; depth of compensation point for photosynthetic activity should not be reduced by more than 10% (Class 2) or more than 20% (Class 3) from the natural seasonal norm (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	10%	WB	Maximum; non-filterable residue; background greater than 100 mg·L^{-1}; man-induced	British Columbia	Pommen 1989
	Narrative	WB	Settleable and suspended solids should not reduce the depth of the compensation point for photosynthetic activity by more than 10% from the seasonally established norm	United States	U.S. EPA 1987

Table A-1. Continued

Variable	Value	Approach	Rationale	Jurisdiction	Reference
Temperature	0°C	WB	No significant increase above natural temperature; water temperatures shall not be altered to a degree that creates or can reasonably be expected to create an adverse effect on aquatic life (3)	Oregon	Oregon Department of Environmental Quality 1989b
	0.5°C	WB	Maximum change per hour; normal daily temperature cycles shall not be altered in amplitude or frequency	Alaska	Alaska Department of Environmental Quality 1989
	1°C	WB	Maximum change from natural level	British Columbia	Pommen 1989
	1°C	WB	Maximum change in weekly average; normal daily temperature cycles shall not be altered in amplitude or frequency	Alaska	Alaska Department of Environmental Quality 1989
	1°C	WB	Maximum change in weekly average resulting from artificial sources, during all seasons of the year; providing the summer maxima are not exceeded; daily temperature cycles characteristic of the water body segment should not be altered in either amplitude or frequency	United States	U.S. EPA 1987
	1°C	WB	Maximum; north of latitude 27°S; acceptable variation in weekly average water temperature due to artificial sources during all seasons of the year, provided that no single value exceeds the highest summer maximum recorded over the previous 5 years inclusive; Class 2 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	2°C	WB	Maximum; south of latitude 27°S; acceptable variation in weekly average water temperature due to artificial sources during all seasons of the year, provided that no single value exceeds the highest summer maximum recorded over the previous 5 years inclusive; Class 2 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	2°C	WB	Maximum; north of latitude 27°S; acceptable variation in weekly average water temperature due to artificial sources during all seasons of the year, provided that no single value exceeds by more than 2°C the highest summer maximum recorded over the previous 5 years inclusive; Class 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	2°C	WB	Maximum increase above natural conditions; guideline for shellfish waters	Europe	Commission of the European Communities 1988
	4°C	WB	Maximum; south of latitude 27°S; acceptable variation in weekly average water temperature due to artificial sources during all seasons of the year, provided that no single value exceeds by more than 2°C the highest summer maximum recorded over the previous 5 years inclusive; Class 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	13.0°C	TT	Maximum; due to human activities, temperature increases shall not, at any time, exceed $t = 8/(T-4)$; Class AA (2,7)	Washington	Washington State 1988
	16.0°C	TT	Maximum; due to human activities, temperature increases shall not, at any time, exceed $t = 12/(T-2)$; Class A (2,7)	Washington	Washington State 1988
	18°C–19°C		Maximum weekly average to protect salmonids	British Columbia	Pommen 1989

Table A-1. Continued

Variable	Value	Approach	Rationale	Jurisdiction	Reference
Temperature	19.0°C	TT	Maximum; due to human activities, temperature increases shall not, at any time, exceed t = 16/T; Class B (2,7)	Washington	Washington State 1988
	22.0°C	TT	Maximum; due to human activities, temperature increases shall not, at any time, exceed t = 20/(T+2); Class C (2,7)	Washington	Washington State 1988
Turbidity	5 NTU	WB	Maximum induced; background less than 50 NTU	British Columbia	Pommen 1989
	5 NTU	WB	Maximum increase; background less than 50 NTU; Classes AA and A (2)	Washington	Washington State 1988
	10 NTU	WB	Maximum increase; background less than 50 NTU; Classes B and C (2)	Washington	Washington State 1988
	10%	WB	Maximum increase; background greater than 50 NTU; Classes AA and A (2)	Washington	Washington State 1988
	10%	WB	Maximum induced; background greater than 50 NTU	British Columbia	Pommen 1989
	10%	WB	Maximum cumulative increase in natural stream turbidity; Jackson Turbidity Units (JTU) measured relative to a control point immediately upstream of the turbidity-causing activity (3)	Oregon	Oregon Department of Environmental Quality 1989b
	10%	WB	Maximum reduction in Secchi disc depth; shall not reduce the depth of the compensation point for photosynthetic activity	Alaska	Alaska Department of Environmental Quality 1989
	20%	WB	Maximum increase; background greater than 50 NTU; Classes B and C (2)	Washington	Washington State 1988
	Narrative	WB	Natural light shall not be significantly reduced at any point outside the initial dilution zone as the result of waste discharge	California	California State Water Resources Control Board 1989

(1) Class 1 = maximum protection for ecosystems and corresponds to water quality of a natural or pristine state; they should not receive any waste discharges whatsoever, nor be affected by man-made changes within the surface or ground watersheds, nor the body of water itself
Class 2 = a high level of protection such that any waste discharges or man-made changes that do occur may be readily assimilated or withstood by the system without any detectable effects on the biota or the structure of the ecosystem to which they belong
Class 3 = a minimal level of protection such that any waste discharge or man-made changes that do occur may lead to changes in the present biota but do not change the nature of the residing biota to the point at which it no longer functions as an ecosystem

(2) Class AA = extraordinary; water quality of this class shall markedly and uniformly exceed the requirements for all or substantially all uses
Class A = excellent; water quality of this class shall meet or exceed the requirements for all or substantially all uses
Class B = good; water quality of this class shall meet or exceed the requirements for most uses
Class C = fair; water quality of this class shall meet or exceed the requirements of selected and essential uses

(3) This includes the North Coast–Lower Columbia Basin, the Mid-Coast Basin, the Umpqua Basin, the South Coast Basin, and the Rogue Basin

(4) The objectives apply to discrete samples from all parts of the water bodies, except from initial dilution zones of effluents. These excluded initial dilution zones are defined as extending up to 100 m downstream (or upstream for the Fraser River, at times of tide reversal) from a discharge, and occupying no more than 25% (50% for the Kitimat River) of the stream width around the discharge point, from the bed of the stream to the surface. These excluded initial dilution zones in marine waters are defined as extending up to 100 m horizontally in all directions, but are not to exceed 25% of the width of the water body. Kitimat Harbour is also defined as an initial dilution zone.

(5) Measurements can be made *in-situ* but must be confirmed in the laboratory if the objective is exceeded.

(6) The percent concentration of pulp mill effluent in the river is calculated by dividing 100 by the effluent dilution ratio. The dilution ratio is calculated by dividing the concentration of sodium in the effluent by the increase in sodium between sites upstream and downstream from the outfall. After complete mixing, the dilution ratio may also be calculated by dividing the river flow by the effluent flow.

(7) A 0.3°C temperature increase will be allowed when natural conditions exceed the given maximum. For purposes hereof, "t" represents the maximum permissible temperature increase measured at a dilution zone boundary, and "T" represents the background temperature as measured at a point(s) unaffected by the discharge and representative of the highest ambient water temperature in the vicinity of the discharge. This is with respect to Classes AA, A, and B waters, provided that temperature increases resulting from non-point source activities do not exceed 2.8°C.

Appendix B
A Compilation of Water Quality Guidelines for the Protection of Aquatic Life: Chemical Variables

Table B-1. A Compilation of Water Quality Guidelines for the Protection of Aquatic Life: Chemical Variables

Variable	Value ($\mu g \cdot L^{-1}$)*	Approach	Rationale	Jurisdiction	Reference
Acenapthene	710	TT	Marine chronic criterion; LOEL	United States	U.S. EPA 1987
	970	TT	Marine acute criterion; LOEL	United States	U.S. EPA 1987
Acrolein	55	TT	Marine acute criterion; LOEL	United States	U.S. EPA 1987
Aldrin	0.003	TT	Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	1.3	TT	Marine acute criterion (2)	United States	U.S. EPA 1987
Aldrin/Dieldrin	0.0019	TT	Marine chronic criterion (2); the sum of aldrin and dieldrin concentrations is compared with the dieldrin criterion	Washington	Washington State 1988
	0.71	TT	Marine acute criterion (2); the sum of aldrin and dieldrin concentrations are compared with the dieldrin criterion	Washington	Washington State 1988
Aluminum, total	20%	WB	Maximum increase; Kitimat Arm (3,4)	British Columbia	Warrington 1987
Ammonia as total-N un-ionized	7	TT	Average; North, Middle, and Main arms of the Fraser River; Sturgeon and Roberts banks (4,5)	British Columbia	Swain and Holms 1985
	30	TT	Maximum; North, Middle, and Main arms of the Fraser River; Sturgeon and Roberts banks (4,5)	British Columbia	Swain and Holms 1985
	600	TT	6-month median; Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	1000	TT	Average (4,5)	British Columbia	Pommen 1989
	1000	TT	Average; Kitimat Arm (4,5)	British Columbia	Warrington 1987
	2000	TT	Maximum; Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	2500	TT	Maximum (4,5)	British Columbia	Pommen 1989
	2500	TT	Maximum; Kitimat Arm (4,5)	British Columbia	Warrington 1987
Antimony, total	200	TT	Hazard	British Columbia	Pommen 1989
Aromatic hydrocarbons	1	TT	Maximum; Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981

BHC = benzene hexachloride
DDE = dichlorodiphenyldichloroethylene
DDT = dichlorodiphenyl trichloroethane
LOEL = lowest-observed-effect level
PAH = polycyclic aromatic hydrocarbon
PCB = polychlorinated biphenyl
SBA = spiked bioassay
TDE = tetrachlorodiphenylethane, or DDD
TT = theoretical toxicological
WB = water background
* Unless otherwise indicated

Table B-1. Continued

Variable	Value ($\mu g \cdot L^{-1}$)*	Approach	Rationale	Jurisdiction	Reference
Aromatic hydrocarbons	10	TT/SBA	Or 0.01 of the lowest measured continuous-flow 96-h LC_{50} for life stages of species identified by the Department as the most sensitive, biologically important species in a particular location, whichever concentration is less	Alaska	Alaska Department of Environmental Quality 1989
Arsenic	8	TT	6-month median; Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	25			United Kingdom	Mance and O'Donnell 1985
	80	TT	80th percentile; Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	500	TT	Maximum of any reading any time; Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
Arsenic (pent)	13	TT	Marine chronic criterion; LOEL	United States	U.S. EPA 1987
	2319	TT	Marine acute criterion; LOEL	United States	U.S. EPA 1987
Arsenic (tri)	36	TT	Total; 4-average; from marine chronic criterion	British Columbia	Pommen 1989
	36	TT	Marine chronic criterion	United States	U.S. EPA 1987
	69	TT	Total; 1-average; from marine acute criterion	British Columbia	Pommen 1989
	69	TT	Marine acute criterion	United States	U.S. EPA 1987
Azinphosmethyl	0.01	TT	Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
Barium, total	500	TT	Minimal risk	British Columbia	Pommen 1989
	1000	TT	Hazard	British Columbia	Pommen 1989
Benzene	700	TT	Marine chronic criterion; LOEL	United States	U.S. EPA 1987
	5100	TT	Marine acute criterion; LOEL	United States	U.S. EPA 1987
Beryllium, total	100	TT	Minimal risk	British Columbia	Pommen 1989
	1500	TT	Hazard	British Columbia	Pommen 1989
BHC	0.34	TT	Marine acute criterion; LOEL	United States	U.S. EPA 1987
Boron, total	5000	WB	Maximum; seawater contains 4500 $\mu g \cdot L^{-1}$	British Columbia	Pommen 1989
Cadium	0.5	TT	Territorial waters and internal coastal waters; determined by the national network and reported to the Commission (6)	Europe	Commission of the European Communities 1988

Table B-1. Continued

Variable	Value ($\mu g \cdot L^{-1}$)*	Approach	Rationale	Jurisdiction	Reference
Cadium	1	TT	Estuaty waters; determined by the national network and reported to the Commission (6)	Europe	Commission of the European Communities 1988
	2.5	TT	Territorial waters and internal coastal waters; minimum requirements to protect aquatic life (6)	Europe	Commission of the European Communities 1988
	3	TT	6-month median; Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	5	TT	Estuary waters; minimum requirements to protect aquatic life (6)	Europe	Commission of the European Communities 1988
	8	TT	Maximum of any reading; Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	9	TT	4-d average; from marine chronic criterion	British Columbia	Pommen 1989
	9.3	TT	Marine chronic criterion (7)	United States	U.S. EPA 1987
	43	TT	1-h average; from marine acute criterion	British Columbia	Pommen 1989
	43	TT	Marine acute criterion (7)	United States	U.S. EPA 1987
Camphechlor	0.005		Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
Carbon tetrachloride	12	TT	(6)	Europe	Commission of the European Communities 1988
	50 000	TT	Marine acute criterion; LOEL	United States	U.S. EPA 1987
Chlordane	0.004	TT	Marine chronic criterion (2)	United States	U.S. EPA 1987
	0.004	TT	Clases 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	0.09	TT	Marine acute criterion (2)	United States	U.S. EPA 1987
Chlorinated benzenes	129	TT	Marine chronic criterion; LOEL	United States	U.S. EPA 1987
	160	TT	Marine acute criterion; LOEL	United States	U.S. EPA 1987
Chlorinated naphthalenes	7.5	TT	Marine acute criterion; LOEL	United States	U.S. EPA 1987

Table B-1. Continued

Variable	Value ($\mu g \cdot L^{-1}$)*	Approach	Rationale	Jurisdiction	Reference
Chlorine	2		Total residual; Main Arm of the Fraser River, Sturgeon and Roberts banks (4,8)	British Columbia	Swain and Holms 1985
	2		For salmonid fish	Alaska	Alaska Department of Environmental Quality 1989
	2	TT	6-month median; Classes 2 amd 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	3		Average level of chlorine-produced oxidants in marine and estuarine water	British Columbia	Pommen 1989
	7.5	TT	Marine chronic criterion (7)	United States	U.S. EPA 1987
	10			Alaska	Alaska Department of Environmental Quality 1989
	13	TT	Marine acute criterion (7)	United States	U.S. EPA 1987
Chlorophenols	0.2	WB	Maximum in water; Fraser River, including the Main Stem, North, Middle, and Main arms (4,9)	British Columbia	Swain and Holms 1985
4-Chlorophenol	29 700	TT	Marine acute criterion; LOEL	United States	U.S. EPA 1987
Chlorpyrifos	0.0056	TT	Marine chronic criterion (7)	United States	U.S. EPA 1987
Chromium total	2	TT	6-month median; Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	7	TT	Maximum for a single reading; Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	15			United Kingdom	Mance and O'Donnell 1985
Chromium (hex), total	50	TT	Marine chronic criterion (7)	United States	U.S. EPA 1987
	50	TT	Total; 4-d average; from marine chronic criterion	British Columbia	Pommen 1989
	1100	TT	Total; 1-h average; from marine acute criterion	British Columbia	Pommen 1989
	1100	TT	Marine acute criterion	United States	U.S. EPA 1987
Chromium (tri)	10 300	TT	Marine acute criterion; LOEL	United States	U.S. EPA 1987
Copper	2	TT/WB	Maximum; total; protection of marine and estuarine life; Kitimat Arm (3,4,5)	British Columbia	Warrington 1987
	2	TT/WB	Total; 30-d average; the form of copper can be modified when detailed knowledge on its bioavailable forms is available	British Columbia	Pommen 1989

Table B-1. Continued

Variable	Value ($\mu g \cdot L^{-1}$)*	Approach	Rationale	Jurisdiction	Reference
Copper	2.9	TT	Marine acute criterion	United States	U.S. EPA 1987
	2.9	TT	Marine chronic criterion	United States	U.S. EPA 1987
	3	TT/WB	Average; total; for hardness < 35 $mg \cdot L^{-1}$; North, Middle, and Main arms of the Fraser River (4,5)	British Columbia	Swain and Holms 1985
	3	TT/WB	Maximum; total; protection of marine and estuarine life; Kitimat Arm (3,4,5)	British Columbia	Warrington 1987
	3	TT/WB	Maximum; total; the form of copper can be modified when detailed knowledge on its bioavailable forms is available	British Columbia	Pommen 1989
	4	TT/WB	Average; total; for hardness > 35 $mg \cdot L^{-1}$; North, Middle, and Main arms of the Fraser River (4,5)	British Columbia	Swain and Holms 1985
	4	TT/WB	Maximum; total; or 20% maximum increase, whichever is greater; for hardness < 35 $mg \cdot L^{-1}$; North, Middle, and Main arms of the Fraser River (4,5)	British Columbia	Swain and Holms 1985
	5	TT	6-month median; Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	5			United Kingdom	Mance and O'Donnell 1985
	6	TT/WB	Maximum; total; or 20% maximum increase, whichever is greater; for hardness > 35 $mg \cdot L^{-1}$; North, Middle, and Main arms of the Fraser River (4,5)	British Columbia	Swain and Holms 1985
	40	TT	Maximum for a single reading; Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	20%	WB	Maximum increase over background; Kitimat Arm (3,4,5)	British Columbia	Warrington 1987
	Narrative	WB	If natural background levels exceed the criterion for aquatic life, the increase in total copper above background to be allowed, if any, should be based on site-specific data	British Columbia	Pommen 1989
Cyanide	1	TT	Marine and acute criterion	United States	U.S. EPA 1987
	1	TT	Marine chronic criterion	United States	U.S. EPA 1987
	1	TT	Kitimat Arm, weak-acid dissociable (4,10)	British Columbia	Warrington 1987
	1	TT	Maximum at any time; unfiltered water; weak-acid dissociable	British Columbia	Pommen 1989
	5	TT	6-month median; Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	10	TT	Maximum; Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981

Table B-1. Continued

Variable	Value ($\mu g \cdot L^{-1}$)*	Approach	Rationale	Jurisdiction	Reference
DDE (DDT metabolite)	14	TT	Marine acute criterion; LOEL	United States	U.S. EPA 1987
DDT	0.001	TT	Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	0.001	TT	Marine chronic criterion	United States	U.S. EPA 1987
	0.13	TT	Marine acute criterion	United States	U.S. EPA 1987
	10	TT	p,p'-DDT (6,11)	Europe	Commission of the European Communities 1988
	25	TT	Total (6,11)	Europe	Commission of the European Communities 1988
Demeton	0.1	TT	Marine chronic criterion	United States	U.S. EPA 1987
Dichlorobenzenes	1970	TT	Marine acute criterion; LOEL	United States	U.S. EPA 1987
1,2-Dichloroethane	113 000	TT	Marine acute criterion; LOEL	United States	U.S. EPA 1987
Dichloroethylenes	224 000	TT	Marine acute criterion; LOEL	United States	U.S. EPA 1987
2,4-Dichlorophenoxy acetic acid	4	TT	Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
Dichloropropane	3040	TT	Marine chronic criterion; LOEL	United States	U.S. EPA 1987
	10 300	TT	Marine acute criterion; LOEL	United States	U.S. EPA 1987
Dichloropropene	790	TT	Marine acute criterion; LOEL	United States	U.S. EPA 1987
Dieldrin	0.0019	TT	Marine chronic criterion (2)	United States	U.S. EPA 1987
	0.003	TT	Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	0.71	TT	Marine acute criterion (2)	United States	U.S. EPA 1987
Dinitrotoluene	370	TT	Marine chronic criterion; LOEL	United States	U.S. EPA 1987
	590	TT	Marine acute criterion; LOEL	United States	U.S. EPA 1987
Endosulfan	0.001	TT	Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	0.0087	TT	Marine chronic criterion (2)	United States	U.S. EPA 1987

Table B-1. Continued

Variable	Value ($\mu g \cdot L^{-1}$)[a]	Approach	Rationale	Jurisdiction	Reference
Endosulfan	0.034	TT	Marine acute criterion (2)	United States	U.S. EPA 1987
Endrin	0.0023	TT	Marine chronic criterion (2)	United States	U.S. EPA 1987
	0.004	TT	Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	0.037	TT	Marine acute criterion (2)	United States	U.S. EPA 1987
Ethylbenzene	430	TT	Marine acute criterion; LOEL	United States	U.S. EPA 1987
Fluoranthene	16	TT	Marine chronic criterion; LOEL	United States	U.S. EPA 1987
	40	TT	Marine acute criterion; LOEL	United States	U.S. EPA 1987
Fluoride	1500	WB	Kitimat Arm (4)	British Columbia	Warrington 1987
	1500	WB	Seawater contains 800–1400 $\mu g \cdot L^{-1}$	British Columbia	Pommen 1989
	2000	TT	6-month median; Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	10 000	TT	Maximum; Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
General	Narrative	TT	Substances shall not individually or in combination exceed 0.01 times the lowest measured 96-h LC_{50} for life stages of species identified by the Department as being the most sensitive, biologically important to the location, or exceed criteria cited in EPA "Quality Criteria for Water" or "Alaska Drinking Water Standard," whichever concentration is less	Alaska	Alaska Department of Environmental Quality 1989
Guthion	0.01	TT	Marine chronic criterion	United States	U.S. EPA 1987
Halomethanes	6400	TT	Marine chronic criterion; LOEL	United States	U.S. EPA 1987
	12 000	TT	Marine acute criterion; LOEL	United States	U.S. EPA 1987
Heptachlor	0.001	TT	Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	0.0036	TT	Marine chronic criterion (2)	United States	U.S. EPA 1987
	0.053	TT	Marine acute criterion (2)	United States	U.S. EPA 1987
Hexachlorobutadiene	32	TT	Marine acute criterion; LOEL	United States	U.S. EPA 1987
Hexachlorocyclo-hexane (Lindane)	0.004	TT	Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981

Table B-1. Continued

Variable	Value ($\mu g \cdot L^{-1}$)*	Approach	Rationale	Jurisdiction	Reference
Hexachlorocyclohexane (Lindane)	0.020		Estuary waters and territorial seawaters; minimum requirements to protect aquatic life (6)	Europe	Commission of the European Communities 1988
	0.16	TT	Marine acute criterion (2)	United States	U.S. EPA 1987
Hexachlorocyclopentadiene	7	TT	Marine acute criterion; LOEL	United States	U.S. EPA 1987
Hexachloroethane	940	TT	Marine acute criterion; LOEL	United States	U.S. EPA 1987
Hydrocarbons, total	10	TT	Classes 2 and 3 (1)	Western Australia	Western Australia Department of Conservation and Environment 1981
	15	TT	Or 0.01 of the lowest measured continuous-flow 96-h LC_{50} for life stages of species identified by the Department as the most sensitive, biologically important species in a particular location, whichever concentration is less	Alaska	Alaska Department of Environmental Quality 1989
Iron	50		Minimal risk (12)	British Columbia	Pommen 1989
	300		Hazard (12)	British Columbia	Pommen 1989
	300		Kitimat Arm (4)	British Columbia	Warrington 1987
Isophorone	12 900	TT	Marine acute criterion; LOEL	United States	U.S. EPA 1987
Lead	2	TT	Total; 30-d average (5)	British Columbia	Pommen 1989
	3	TT	Total; 80th percentile (5)	British Columbia	Pommen 1989
	3	TT	Average; total; North, Middle, and Main arms of the Fraser River (4,5)	British Columbia	Swain and Holms 1985
	5.6	TT	Marine chronic criterion (7)	United States	U.S. EPA 1987
	8	TT	6-month median; Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	9	TT	Average; Kitimat Arm (3,4,5)	British Columbia	Warrington 1987
	10	TT	Maximum; total; North, Middle, and Main arms of the Fraser River (4,5)	British Columbia	Swain and Holms 1985
	25			United Kingdom	Mance and O'Donnell 1985
	80	TT	80th percentile; Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environmental 1981
	140	TT	Maximum; total (5)	British Columbia	Pommen 1989
	140	TT	Marine acute criterion (7)	United States	U.S. EPA 1987

Table B-1. Continued

Variable	Value ($\mu g \cdot L^{-1}$)*	Approach	Rationale	Jurisdiction	Reference
Lead	200	TT	Maximum at any time; Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	220	TT/WB	Maximum, or 20% maximum increase, whichever is greater; Kitimat Arm (3,4,5)	British Columbia	Warrington 1987
Malathion	0.1	TT	Marine chronic criterion	United Stated	U.S. EPA 1987
Maldison	0.1	TT	Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
Manganese	20		Total; minimal risk (13)	British Columbia	Pommen 1989
	100		Hazard (13)	British Columbia	Pommen 1989
Mercury	0.02	TT	30-d average; total mercury (5)	British Columbia	Pommen 1989
	0.025	TT	Marine chronic criterion (7)	United States	U.S. EPA 1987
	0.14	TT	6-month median; Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	0.3	TT	Territorial seawaters and internal coastal waters; elemental mercury and its compounds (6)	Europe	Commission of the European Communities 1988
	0.5	TT	Estuary waters; elemental mercury and its compounds (6)	Europe	Commission of the European Communities 1988
	1.4	TT	80th percentile; Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	2	TT	Maximum; total mercury (5)	British Columbia	Pommen 1989
	2.1	TT	Marine acute criterion (7)	United States	U.S. EPA 1987
	3	TT	Maximum at any time; Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
Methoxychlor	0.03	TT	Marine chronic criterion	United States	U.S. EPA 1987
	0.03	TT	Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
Mirex	0.001	TT	Marine chronic criterion	United States	U.S. EPA 1987
Naphthalene	2350	TT	Marine acute criterion; LOEL	United States	U.S. EPA 1987
Nickel	8.3		4-d average	British Columbia	Pommen 1989
	8.3	TT	Marine chronic criterion (7)	United States	U.S. EPA 1987

Table B-1. Continued

Variable	Value ($\mu g \cdot L^{-1}$)*	Approach	Rationale	Jurisdiction	Reference
Nickel	20	TT	6-month median; Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	30			United Kingdom	Mance and O'Donnell 1985
	75		Maximum	British Columbia	Pommen 1989
	75	TT	Marine acute criterion (7)	United States	U.S. EPA 1987
	200	TT	80th percentile; Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	450	TT	Maximum at any time; Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
Nitrite–N	20	TT	Average; Kitimat River downstream of the District of Kitimat sewage discharge (4,5)	British Columbia	Warrington 1987
	60	TT	Maximum; Kitimat River downstream of the District of Kitimat sewage discharge (4,5)	British Columbia	Warrington 1987
Nitrobenzene	6680	TT	Marine acute criterion; LOEL	United States	U.S. EPA 1987
Nitrophenols	4850	TT	Marine acute criterion; LOEL	United States	U.S. EPA 1987
Nitrosamines	3 300 000	TT	Marine acute criterion; LOEL	United States	U.S. EPA 1987
Nutrients and other biostimulants	Narrative		The load to receiving waters should not cause excessive or nuisance growths of algae or other aquatic plants or deleterious reductions in dissolved oxygen concentrations in those waters; Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	Narrative		Shall not cause objectionable aquatic growths or degrade indigenous biota	California	California State Water Resources Control Board 1989
PAHs	300	TT	Marine acute criterion; LOEL	United States	U.S. EPA 1987
Parathion	0.04	TT	Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
PCBs	0.001	TT	Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	0.001	TT	Maximum in water	British Columbia	Pommen 1989
	0.03	TT	Marine chronic criterion (2)	United States	U.S. EPA 1987
	10	TT	Marine acute criterion (2)	United States	U.S. EPA 1987
Pentachlorinated ethanes	281	TT	Marine chronic criterion; LOEL	United States	U.S. EPA 1987

Table B-1. Continued

Variable	Value ($\mu g \cdot L^{-1}$)*	Approach	Rationale	Jurisdiction	Reference
Pentachlorinated ethanes	390	TT	Marine acute criterion; LOEL	United States	U.S. EPA 1987
Pentachlorophenol	2	TT	2,3,4,5,6-pentachloro-1-hydroxybenzene and its salts (6,14)	Europe	Commission of the European Communities 1988
	7.9	TT	Marine chronic criterion; LOEL (7)	United States	U.S. EPA 1987
	13	TT	Marine acute criterion (7)	United States	U.S. EPA 1987
Pesticides, other	Narrative	TT	0.01 of the 96-h LC_{50}'s for selected test species; maximum; Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
Phenol	1	TT	Maximum, to prevent fish tainting; lowest toxic effects are 27-d LC_{50}'s for rainbow trout eggs and larvae of 70 $\mu g \cdot L^{-1}$ for betanaphtol and 120 $\mu g \cdot L^{-1}$ for phenol	British Columbia	Pommen 1989
	5800	TT	Marine acute criterion; LOEL	United States	U.S. EPA 1987
Phenolic compounds	300	TT	6-month median; Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
Phosphorus, elemental	0.1	TT	Marine chronic criterion	United States	U.S. EPA 1987
Phthalate esters	3.4	TT	Marine chronic criterion; LOEL	United States	U.S. EPA 1987
	2944	TT	Marine acute criterion; LOEL	United States	U.S. EPA 1987
Radioactive substances	Narrative	TT	Should not be present in concentrations that are deleterious to human, plant, animal, or aquatic life or that result in the accumulation of radioactive substances in the food web to an extent that presents a hazard to human, plant, animal, or aquatic life; Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	Narrative		Radioactive waste discharge shall not degrade marine life	California	California State Water Resources Control Board 1989
Selenium	54	TT	24-h average; based on marine chronic criterion; use caution, marine criterion appears high	British Columbia	Pommen 1989
	54	TT	Marine chronic criterion (2)	Washington	Washington State 1988
	71	TT	Marine chronic criterion (2)	United States	U.S. EPA 1989
	300	TT	Marine acute criterion (2)	United States	U.S. EPA 1989
	410	TT	Marine acute criterion (2)	Washington	Washington State 1988
	410	TT	Maximum; based on marine acute criterion; use caution, marine criterion appears high	British Columbia	Pommen 1989

Table B-1. Continued

Variable	Value ($\mu g \cdot L^{-1}$)*	Approach	Rationale	Jurisdiction	Reference
Silver	0.45	TT	6-month median; Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	2.3	TT	Marine acute criterion (2)	United States	U.S. EPA 1987
	2.3	TT	Maximum; use caution, no chronic toxicity data for sensitive marine species	British Columbia	Pommen 1989
	4.5	TT	80th percentile; Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	10	TT	Maximum at any time; Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
Sulphide, as hydrogen sulphide	2	TT	Marine chronic criterion	United States	U.S. EPA 1987
	2		Kitimat River downstream from the District of Kitimat sewage discharge (4)	British Columbia	Warrington 1987
	2	TT	Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	2		Undissociated	British Columbia	Pommen 1989
Surfactants	Narrative	TT	0.01 of the 96-h LC_{50}; for the test organism; Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
TDE (DDT metabolite)	3.6	TT	Marine acute criterion; LOEL	United States	U.S. EPA 1987
1,1,2,2-Tetrachloroethane	9020	TT	Marine acute criterion; LOEL	United States	U.S. EPA 1987
Tetrachloroethylene	450	TT	Marine chronic criterion; LOEL	United States	U.S. EPA 1987
	10 200	TT	Marine acute criterion; LOEL	United States	U.S. EPA 1987
2,3,5,6-Tetrachlorophenol	440	TT	Marine chronic criterion; LOEL	United States	U.S. EPA 1987
Thallium	2130	TT	Marine acute criterion; LOEL	United States	U.S. EPA 1987
Toluene	5000	TT	Marine chronic criterion; LOEL	United States	U.S. EPA 1987
	6300	TT	Marine acute criterion; LOEL	United States	U.S. EPA 1987
Toxaphene	0.0002	TT	Marine chronic criterion (7)	United States	U.S. EPA 1987

Table B-1. Continued

Variable	Value ($\mu g \cdot L^{-1}$)*	Approach	Rationale	Jurisdiction	Reference
Toxaphene	0.21	TT	Marine chronic criterion (7)	United States	U.S. EPA 1987
Toxic substances, other	Narrative	TT/WB	Toxic, radioactive, or deleterious material concentrations shall be below those that may adversely affect characteristic water uses, cause acute or chronic conditions to the aquatic biota, or adversely affect public health; and shall not be introduced above natural background levels; Classes AA, A, B, and C (15)	Washington	Washington State 1988
	Narrative	TT	No material should be present in an amount exceeding 0.01 of 96-h LC_{50} value for the test organism; Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
1,1,1-Trichloroethane	31 200	TT	Marine acute criterion; LOEL	United States	U.S. EPA 1987
Trichloroethylene	2000	TT	Marine acute criterion; LOEL	United States	U.S. EPA 1987
Uranium, total	100	TT	Minimal risk	British Columbia	Pommen 1989
	500	TT	Hazard	British Columbia	Pommen 1989
Vanadium, total	10 000	TT	96-h LC_{50} for some marine fish	British Columbia	Pommen 1989
Zinc	20	TT	6-month median; Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	40			United Kingdom	Mance and O'Donnell 1985
	50		Average; total; North, Middle, and Main arms of the Fraser River (4,5)	British Columbia	Swain and Holms 1985
	86	TT	Marine chronic criterion (7)	United States	U.S. EPA 1987
	86	TT	4-d average; total zinc	British Columbia	Pommen 1989
	95	TT	Marine acute criterion (7)	United States	U.S. EPA 1987
	95	TT	1-h average; total zinc	British Columbia	Pommen 1989
	100	TT	Maximum; total; North, Middle and Main arms of the Fraser River (4,5)	British Columbia	Swain and Holms 1985
	200	TT	Maximum at any time; Classes 2 and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981

(1) Class 1 = maximum protection for ecosystems and corresponds to water quality of a natural or pristine state; they should not receive any waste discharge whatsoever, nor be affected by man-made changes within the surface or ground watersheds, nor the body of water itself
Class 2 = a high level of protection such that any waste discharge or man-made changes that do occur may be readily assimilated or withstood by the system without any detectable effects on the biota or the structure of the ecosystem to which they belong
Class 3 = a minimal level of protection such that any waste discharge or man-made changes that do occur may lead to changes in the present biota but do not change the nature of the residing biota to the point at which it no longer functions as an ecosystem

(2) Acute criterion: instantaneous concentration not to be exceeded at any time.
Chronic criterion: a 24-h average not to be exceeded.

(3) The increase is over levels measured at a background site or site upstream from a discharge or series of discharges and as close to them as possible, or in an unaffected part of the marine environment. The increase applies to downstream or affected levels.

(4) The objectives apply to discrete samples from all parts of the water bodies, except from initial dilution zones of effluents. These excluded initial dilution zones are defined as extending up to 100 m downstream (or upstream for the Fraser River at times of tide reversal) from a discharge, and occupying no more than 25% (50% for the Kitimat River) of the stream width around the discharge point, from the bed of the stream to the surface. These excluded initial dilution zones in marine waters are defined as extending up to 100 m horizontally in all directions, but not to exceed 25% of the width of the water body. Kitimat Harbour is also defined as an initial dilution zone.

(5) The average is calculated from at least five weekly samples taken in a 30-d period.

(6) Quality objectives refer to the arithmetic mean of the results obtained over a year. Samples must be taken at a point sufficiently close to the discharge point to be representative of the quality of the aquatic environment in the area affected by the discharges, and the frequency of sampling must be sufficient to show any changes in the aquatic environment, having regard in particular to natural variations in hydrological conditions.

(7) Acute criterion: a 1-h average concentration not to be exceeded more than once every 3 years.
Chronic criterion: a 4-d average concentration not to be exceeded more than once every 3 years.

(8) Because the objective is less than the minimum detectable concentration, it will be necessary to estimate the receiving water concentration using effluent load and stream flow. The objective applies only if sewage effluent is chlorinated.

(9) The term chlorophenol means the sum of tri-, tetra-, and pentachlorophenol that may be present in water, sediment, or fish. The maximum value should not be exceeded in bottom surface sediments taken in any part of the sub-basin, except in the initial dilution zones of effluents. The average of at least three replicate sediment samples taken from the same site should be used to check the objective. The objective applies only to fish muscle tissue, not the whole fish or organs, of a fish of any species caught in any part of the sub-basin, including the initial dilution zones of effluents.

(10) The minimum detectable concentration for cyanide is 0.005 $mg \cdot L^{-1}$ at this time: until detection limits can be improved, measurements reported as <0.005 $mg \cdot L^{-1}$ (as CN) will be accepted. However, calculated receiving water cyanide concentrations should not exceed the objective. Measurements of a strong-acid dissociable cyanide should also be made to check whether the possible photolysis or iron-cyanide complexes may produce unacceptable levels of weak-acid dissociable cyanide.

(11) Standstill: the concentration of DDT in the aquatic environment, sediments and/or molluscs and/or shellfish and/or fish must not increase significantly with time.
The sum of the isomers 1,1,1-trichloro-2,2-bis(p-chlorophenyl)ethane; 1,1,1-trichloro-(O-chlorophenyl)-2-(p-chlorophenyl)ethane;1,1,1-dichloro-2,2-bis(p-chlorophenyl)ethylene; and 1,1,1-dichloro-2,2-bis(p-chlorophenyl)ethane.

(12) Dissolved iron and iron precipitates are the important forms to consider. Total iron is often high because of iron content of suspended sediment and thus is not as important.

(13) Dissolved manganese and manganese precipitates are the important forms to consider. Total manganese is often high because of manganese content of suspended sediment and thus is not as important.

(14) Standstill: the concentration of pentachlorophenol in sediments and/or molluscs and/or shellfish and/or fish must not increase significantly with time.

(15) Class AA = extraordinary; water quality of this class shall markedly and uniformly exceed the requirements for all or substantially all uses
Class A = excellent; water quality of this class shall meet or exceed the requirements for all or substantially all uses
Class B = good; water quality of this class shall meet or exceed the requirements for most uses
Class C = fair; water quality of this class shall meet or exceed the requirements of selected and essential uses

Appendix C
A Compilation of Water Quality Guidelines for Recreation and Aesthetics: General Variables

Table C-1. A Compilation of Water Quality Guidelines for the Recreation and Aesthetics: General Variables

Variable	Value	Rationale	Jurisdiction	Reference
Aesthetic values	Narrative	All waters should be free from substances attributable to wastewater or other discharges in amounts that would interfere with the existence of life forms of aesthetic value. To include: a) materials that will settle to form objectionable deposits; b) floating debris, oil, scum, and other matter; c) substances producing objectionable colour, odour, taste, or turbidity; d) substances and conditions or combinations thereof in concentrations that produce undesirable aquatic life	Canada	Health and Welfare Canada 1990
	Narrative	All waters shall be free from substances attributable to wastewater or other discharges that: a) settle to form objectionable deposits; b) float as debris, scum, oil, or other matter to form nuisances; c) produce objectionable colour, odour, taste, or turbidity; d) injure or are toxic to or produce adverse physiological responses in humans, animals, or plants; and e) produce undesirable or nuisance aquatic life	United States	U.S. EPA 1987
	Narrative	Shall not be impaired by the presence of materials or their effects, excluding those of natural origin, which offend the senses of sight, smell, touch, or taste; Classes AA and A (1)	Washington	Washington State 1988
	Narrative	Shall not be reduced by dissolved, suspended, floating, or submerged matter not attributed to natural causes, so as to affect water use or taint the flesh of edible species; Class B (1)	Washington	Washington State 1988
Bacterial characteristics	0	Mandatory; *Salmonella*; bathing waters	Europe	Commission of the European Communities 1988
	0 PFU/L	Mandatory; *enteroviruses*; bathing waters	Europe	Commission of the European Communities 1988
	2/100 mL	Maximum; *Pseudomonas aeruginosa*; primary contact (2, 3)	British Columbia	Pommen 1989
	10/100 mL	Maximum; 75th percentile (2); *Pseudomonas aeruginosa*; secondary contact	British Columbia	Pommen 1989

MPN = mean probable number
NTU = nephelometric turbidity unit
PFU = plaque-forming unit

Table C-1. Continued

Variable	Value	Rationale	Jurisdiction	Reference
Bacterial characteristics	12/100 mL	Maximum; geometric mean enterococcus density, 6-month period (2); at any shore station; water contact standards	California	California State Water Resources Control Board 1989
	20/100 mL	Maximum; geometric mean (2,3); enterococci; primary contact	British Columbia	Pommen 1989
	24/100 mL	Maximum geometric mean enterococcus density, 30-d period (2); at any shore station; water contact standards	California	California State Water Resources Control Board 1989
	35/100 mL	Maximum; geometric mean enterococcus density (2); resampling should be performed when any sample exceeds 70 enterococci/100 mL (4)	Canada	Health and Welfare Canada 1990
	35/100 mL	Maximum; geometric mean enterococcus density (2); marine water bathing; no sample should exceed a one-sided confidence limit (5)	United States	U.S. EPA 1987
	100/100 mL	Maximum; geometric mean (2); enterococci; secondary contact recreation and crustaceans	British Columbia	Pommen 1989
	100 MPN/100 mL	Maximum; guideline for bathing waters; fecal streptococci	Europe	Commission of the European Communities 1988
	Narrative	It is recommended that *Pseudomonas aeruginosa* be used as a parameter to assist in interpreting results of sanitary and microbiological surveys	Canada	Health and Welfare Canada 1990
	Narrative	Sampling for *Staphylococcus aureus* should be carried out when there is epidemiological or other evidence of its presence in the water, or in order to assess the hazards of excessive utilization of the water with possible person-to-person transfer of the pathogen	Canada	Health and Welfare Canada 1990
	Narrative	It is recommended that *Salmonella* be used as a parameter to assist in intepreting the results of sanitary and microbiological surveys	Canada	Health and Welfare Canada 1990
	Narrative	Sampling for *Shigella* should be carried out when there is epidemiological or other evidence of its presence in the water, or in order to assess the hazards of excessive utilization of the water with possible person-to-person transfer of the pathogen	Canada	Health and Welfare Canada 1990
	Narrative	It is recommended that sampling for *Aeromonas* in waters used for recreation be considered only for epidemiological investigations	Canada	Health and Welfare Canada 1990

Table C-1. Continued

Variable	Value	Rationale	Jurisdiction	Reference
Bacterial characteristics	Narrative	Sampling for *Campylobacter jejuni* should be carried out when there is epidemiological or other evidence of its presence in the water, or in order to assess the hazards of excessive utilization of the water with possible person-to-person transfer of the pathogen	Canada	Health and Welfare Canada 1990
Chemical oxygen demand	2 $mg \cdot L^{-1}$	Maximum; bathing; conservation of scenic points and other natural resources	Japan	Japan Environment Agency 1987
	8 $mg \cdot L^{-1}$	Maximum; conservation of environment, up to limits at which no unpleasantness is caused to the people in their daily lives, including a walk along the shore	Japan	Japan Environment Agency 1987
Coliforms, total	500 MPN/100 mL	Maximum; guideline for bathing waters	Europe	Commission of the European Communities 1988
	1000 MPN/100 mL	Maximum number of coliform groups; bathing; conservation of scenic points and other natural resources	Japan	Japan Environment Agency 1987
	1000 MPN/100 mL	Maximum; 80th percentile; 30-d sampling period; water contact standards	California	California State Water Resources Control Board 1989
	10 000 MPN/100 mL	Maximum; for single sample, when verified by a repeat sample taken within 48 h water contact standards	California	California State Water Resources Control Board 1989
	10 000 MPN/100 mL	Maximum; mandatory for bathing waters	Europe	Commission of the European Communities 1988
Colour	15 units	Desirable	British Columbia	Pommen 1989
	15 units	Contact recreation	Alaska	Alaska Department of Environmental Quality 1989
	100 units	Maximum	British Columbia	Pommen 1989
	Narrative	Surface waters shall be free of substances producing objectionable colour; secondary recreation	Alaska	Alaska Department of Environmental Quality 1989
	Narrative	Waste discharge shall not cause aesthetically undesirable discoloration of the ocean surface	California	California State Water Resources Control Board 1989
	Narrative	Waters shall be virtually free from substances producing objectionable colour for aesthetic purposes	United States	U.S. EPA 1987

Table C-1. Continued

Variable	Value	Rationale	Jurisdiction	Reference
Colour	Narrative	No abnormal change in colour; mandatory for bathing waters	Europe	Commission of the European Communities 1988
Dissolved gas, total	110%	The concentration shall not exceed this percent saturation at any point of sample collection; contact and secondary recreation	Alaska	Alaska Department of Environmental Quality 1989
Dissolved oxygen (DO)	2.0 $mg \cdot L^{-1}$	Minimum; for bathing (6)	British Columbia	Pommen 1989
	2.0 $mg \cdot L^{-1}$	Minimum; conservation of environment, up to the limits at which no unpleasantness is caused to the people in their daily lives, including a walk along the shore	Japan	Japan Environment Agency 1987
	4.0 $mg \cdot L^{-1}$	Minimum; below 1 m surface; except when natural conditions cause this value to be depressed; for coastal waters; primary and secondary recreation	Alaska	Alaska Department of Environmental Quality 1989
	4.0 $mg \cdot L^{-1}$	Minimum; Class C (1)	Washington	Washington State 1988
	5.0 $mg \cdot L^{-1}$	Minimum; except when natural conditions cause this value to be depressed; estuaries and tidal tributaries; primary and secondary recreation	Alaska	Alaska Department of Environmental Quality 1989
	5.0 $mg \cdot L^{-1}$	Minimum; Class B (1)	Washington	Washington State 1988
	6.0 $mg \cdot L^{-1}$	Minimum; to depth of 1 m; except when natural conditions cause this value to be depressed; for coastal waters; primary and secondary recreation	Alaska	Alaska Department of Environmental Quality 1989
	6.0 $mg \cdot L^{-1}$	Minimum; Class A (1)	Washington	Washington State 1988
	7.0 $mg \cdot L^{-1}$	Minimum; Class AA (1)	Washington	Washington State 1988
	7.5 $mg \cdot L^{-1}$	Minimum; bathing and conservation of scenic points and other natural resources	Japan	Japan Environment Agency 1987
	7.8 $mg \cdot L^{-1}$	Minimum; Kitimat River downstream from District of Kitimat sewage discharge; secondary contact recreation (6)	British Columbia	Warrington 1987
	80%–120%	Saturation; guideline for bathing waters	Europe	Commission of the European Communities 1988
	Narrative	When natural conditions such as upwelling occur causing the DO to be depressed near or below the minimum level for a given class; natural DO levels can be degraded by up to 0.2 $mg \cdot L^{-1}$ human activities	Washington	Washington State 1988

Table C-1. Continued

Variable	Value	Rationale	Jurisdiction	Reference
Fecal coliforms (FC) (7)	14 MPN/100 mL	Maximum; geometric mean; primary contact	Washington	Washington State 1989
	20 FC/100 mL	Maximum; mean; primary contact	Alaska	Alaska Department of Environmental Quality 1989
	40 FC/100 mL	Maximum; 90th percentile; primary contact	Alaska	Alaska Department of Environmental Quality 1989
	43 MPN/100 mL	Maximum; 90th percentile; Classes AA and A (1)	Washington	Washington State 1988
	50 MPN/100 mL	Minimum; median; secondary contact (8)	W. Australia	Western Australia Department of Conservation and Environment 1981
	100 MPN/100 mL	Maximum; 50th percentile; bathing waters	Mediterranean	World Health Organization 1985
	100 MPN/100 mL	Maximum; guideline for bathing waters	Europe	Commission of the European Communities 1988
	100 MPN/100 mL	Maximum; geometric mean; Class B (1)	Washington	Washington State 1988
	150 MPN/100 mL	Minimum; 80th percentile; secondary contact (8)	W. Australia	Western Australia Department of Conservation and Environment 1981
	150 MPN/100 mL	Maximum; median; direct contact (9)	W. Australia	Western Australia Department of Conservation and Environment 1981
	200 MPN/100 mL	Maximum; geometric mean; primary contact (2,3,6)	British Columbia	Pommen 1989
	200 FC/100 mL	Maximum; mean; secondary contact	Alaska	Alaska Department of Environmental Quality 1989
	200 MPN/100 mL	Maximum; geometric mean (2); water contact standards	California	California State Water Resources Control Board 1989
	200 MPN/100 mL	Maximum; 90th percentile; Class B (1)	Washington	Washington State 1988
	200 MPN/100 mL	Maximum; geometric mean; Class C (1)	Washington	Washington State 1988
	400 MPN/100 mL	Maximum; 90th percentile; primary contact (2,3,6)	British Columbia	Pommen 1989
	400 FC/100 mL	Maximum; 90th percentile; secondary contact	Alaska	Alaska Department of Environmental Quality 1989
	400 MPN/100 mL	Maximum; 90th percentile; total of samples taken during any 60-d period; water contact standards	California	California State Water Resources Control Board 1989

Table C-1. Continued

Variable	Value	Rationale	Jurisdiction	Reference
Fecal coliforms (FC) (7)	400 MPN/100 mL	Maximum; 90th percentile; Class C (1)	Washington	Washington State 1988
	500 MPN/100 mL	Maximum; 80th percentile; direct contact (9)	W. Australia	Western Australia Department of Conservation and Environment 1981
	1000 MPN/100 mL	Maximum; 90th percentile (2); bathing waters	Mediterranean	World Health Organization 1985
	2000 MPN/100 mL	Maximum; mandatory for bathing waters	Europe	Commission of the European Communities 1988
Fecal material	Narrative	The water in bathing and swimming areas should be protected against direct contamination with fresh fecal material of human or domesticated animal origin	W. Australia	Western Australia Department of Conservation and Environment 1981
Light penetration	Narrative	Water should be sufficiently clear that a Secchi disc is visible at a minimum depth of 1.2 m	Canada	Health and Welfare Canada 1990
	Narrative	A Secchi disc should be visible to a depth of 2 m except in "learn to swim" areas, where a Secchi disc should be visible on the bottom; direct contact	W. Australia	Western Australia Department of Conservation and Environment 1981
	Narrative	Natural light shall not be significantly reduced at any point outside the initial dilution zone as the result of waste discharge	California	California State Water Resources Control Board 1989
Mineral oils	0.3 $mg \cdot L^{-1}$	Maximum; guideline for bathing waters	Europe	Commission of the European Communities 1988
	Narrative	Mandatory; no film visible on the surface of the water and no odour; bathing waters	Europe	Commission of the European Communities 1988
Nuisance organisms	Narrative	Some biota that could be a nuisance to bathers if present in large numbers (e.g., leaches, mussels, biting insects, floating or rooted aquatic plants, phytoplankton, periphyton, and growths such as sewage fungus) should be absent from areas intended for development as bathing beaches	Canada	Health and Welfare Canada 1990
Oil, grease, and petroleum hydrocarbons	Narrative	Should not be present in concentrations that: a) can be detected as a visible film, sheen, or discoloration on the surface; b) can be detected by odour; c) can form deposits on shorelines and bottom sediments that are detectable by sight or odour	Canada	Health and Welfare Canada 1990
	Not detectable	By sight or smell	British Columbia	Pommen 1989

Table C-1. Continued

Variable	Value	Rationale	Jurisdiction	Reference
Oil, grease, and petroleum hydrocarbons	Not visible		California	California State Water Resources Control Board 1989
	Narrative	Shall not cause a film, sheen, or discoloration of the surface or floor of the water body or adjoining shoreline; surface waters shall be virtually free from floating oils; contact and secondary recreation	Alaska	Alaska Department of Environmental Quality 1989
pH units	5.0–9.0	Acceptable	British Columbia	Pommen 1989
	5.0–9.0	Guideline for total body contact recreation, for waters with very low buffering capacity	Canada	Health and Welfare Canada 1990
	5.0–9.0	Secondary contact; if the natural pH condition is outside this range, substances shall not be added that cause any increase in buffering capacity of the water	Alaska	Alaska Department of Environmental Quality 1989
	6.0–9.0	Mandatory for bathing waters	Europe	Commission of the European Communities 1988
	6.5–8.3	Desirable	British Columbia	Pommen 1989
	6.5–8.5	Guideline for total body contact recreation	Canada	Health and Welfare Canada 1990
	6.5–8.5	Primary contact; if the natural pH condition is outside this range, substances shall not be added that cause any increase in buffering capacity of the water	Alaska	Alaska Department of Environmental Quality 1989
	6.5–8.5	Except for waters with a low buffering capacity where a range of pH between 5.0 and 9.0 units may be tolerated	W. Australia	Western Australia Department of Conservation and Environment 1981
	6.5–9.0	Kitimat River downstream of the District of Kitimat sewage discharge; secondary contact (6)	British Columbia	Warrington 1987
	6.5–9.0	With a man-caused variation of less than 0.5 units for Class C (1)	Washington	Washington State 1988
	7.0–8.3	Conservation of environment, where no unpleasantness is caused to the people in their daily lives, including a walk along the shore	Japan	Japan Environment Agency 1987
	7.0–8.5	With a man-caused variation of less than 0.2 units for Class AA; less than 0.5 units for Classes A and B (1)	Washington	Washington State 1988
	7.8–8.3	Bathing; conservation of scenic points and other natural resources	Japan	Japan Environment Agency 1987

Table C-1. Continued

Variable	Value	Rationale	Jurisdiction	Reference
Physical hazards	Narrative	Bathing and swimming waters should be free of submerged bodies and other subsurface hazards; direct contact recreation	W. Australia	Western Australia Department of Conservation and Environment 1981
Phytoplankton	Narrative	Water containing a blue-green or turquoise scum is indicative of an algal bloom; such waters should be avoided because of reduced clarity and the possible presence of algal toxins	Canada	Health and Welfare Canada 1990
Radioactivity	Narrative	Shall not exceed the concentrations specified in the "Alaska Drinking Water Standards" and shall not exceed limits specified in Title 10 "Code of Federal Regulations, Part 20"; contact and secondary recreation	Alaska	Alaska Department of Environmental Quality 1989
	Narrative	The waters should not contain radioactive substances in such concentrations as to be deleterious to man if small quantities are ingested	W. Australia	Western Australia Department of Conservation and Environment 1981
Residues	Narrative	Shall not alone or in combination with other substances make the water unfit or unsafe for use; cause a film, sheen, or discoloration on the surface of the water of an adjoining shoreline; or cause a sludge, solid, or emulsion to be deposited beneath or upon the surface of the water, within the water column, on the bottom, or upon adjoining shorelines; contact and secondary recreation	Alaska	Alaska Department of Environmental Quality 1989
	Narrative	Floating particulates shall not be visible; the rate of deposition of inert solids and the characteristics of inert solids in ocean sediments shall not be changed such that benthic communities are degraded	California	California State Water Resources Control Board 1989
Salinity	5–20 $g \cdot L^{-1}$	NaCl or equivalent (9 $g \cdot L^{-1}$ is ideal)	British Columbia	Pommen 1989
Sediment	Narrative	No measurable increase in concentrations above background; contact recreation	Alaska	Alaska Department of Environmental Quality 1989
	Narrative	Shall not pose hazards to incidental human contact or cause interferences with the use; secondary recreation	Alaska	Alaska Department of Environmental Quality 1989
Solids, floatable and settleable	Narrative	Debris resulting from human activity should not be visible	British Columbia	Pommen 1989
	None	Guideline for bathing waters	Europe	Commission of the European Communities 1988

Table C-1. Continued

Variable	Value	Rationale	Jurisdiction	Reference
Suspended solids	10 $mg \cdot L^{-1}$	Maximum increase; Kitimat Arm; when background is less than 100 $mg \cdot L^{-1}$, primary and secondary contact (10)	British Columbia	Warrington 1987
	10%	Maximum increase; Kitimat Arm, when background is greater than 100 $mg \cdot L^{-1}$, primary and secondary contact (10)	British Columbia	Warrington 1987
Temperature	15°C–35°C	Range for bathing	British Columbia	Pommen 1989
	13.0°C	Maximum; due to human activities, temperature increases shall not, at any time, exceed $t = 8/(T-4)$; Class AA (1,11)	Washington	Washington State 1988
	16.0°C	Maximum; due to human activities, temperature increases shall not, at any time, exceed $t = 12/(T-2)$; Class A (1,11)	Washington	Washington State 1988
	19.0°C	Maximum; due to human activities, temperature increases shall not, at any time, exceed $t = 16/T$; Class B (1,11)	Washington	Washington State 1988
	22.0°C	Maximum; due to human activities, temperature increases shall not, at any time, exceed $t = 20/(T+2)$; Class C (1,11)	Washington	Washington State 1988
	Narrative	The thermal characteristics of waters used for bathing and swimming should not cause an appreciable increase or decrease in the deep body temperature of bathers and swimmers	Canada	Health and Welfare Canada 1990
Transparency	1 m	Mandatory for bathing waters	Europe	Commission of the European Communities 1988
	2 m	Guideline for bathing waters	Europe	Commission of the European Communities 1988
Turbidity	5 NTU	Maximum increase over natural turbidity when this is less than 50 NTU	Canada	Health and Welfare Canada 1990
	5 NTU	Induced turbidity; background < 50 NTU (12)	British Columbia	Pommen 1989
	5 NTU	Maximum increase; Kitimat Arm: background <50 NTU; primary and secondary contact (6,10)	British Columbia	Warrington 1987
	5 NTU	Maximum increase; background <50 NTU; Classes AA and A (1)	Washington	Washington State 1988
	10 NTU	Maximum increase; background < 50 NTU; Classes B and C (1)	Washington	Washington State 1988

Table C-1. Continued

Variable	Value	Rationale	Jurisdiction	Reference
Turbidity	25 NTU	Contact and secondary recreation	Alaska	Alaska Department of Environmental Quality 1989
	10%	Induced turbidity; background > 50 NTU (12)	British Columbia	Pommen 1989
	10%	Maximum increase; Kitimat Arm; background > 50 NTU; primary and secondary contact (6,10)	British Columbia	Warrington 1987
	10%	Maximum increase; background > 50 NTU; Classes AA and A (1)	Washington	Washington State 1988
	20%	Maximum increase; background > 50 NTU; Classes B and C (1)	Washington	Washington State 1988
	Narrative	Natural light shall not be significantly reduced at any point outside the initial dilution zone as the result of the discharge of waste	California	California State Water Resources Control Board 1989
Viruses	Narrative	Sampling for viruses should be conducted when there is epidemiological or other evidence of their presence in the water, or in order to assess the hazards of excessive utilization of the water with possible person-to-person transfer of pathogens	Canada	

(1) Class AA = extraordinary; water quality of this class shall markedly and uniformaly exceed the requirements for all or substantially all uses; primary contact recreation
Class A = excellent; water quality of this class shall meet or exceed the requirements for all substantially all uses; primary contact recreation
Class B = good; water quality of this class shall meet or exceed the requirements for most uses; secondary contact recreation
Class C = fair; water quality of this class shall meet or exceed the requirements of selected and essential uses; secondary contact recreation

(2) Median and geometric means are calculated from at least five samples taken in a 30-d period. Ten samples are required for 90th percentiles.

(3) These primary contact recreation criteria may be subject to revision depending upon the future results of a federal–provincial study group on Canadian recreational water quality.

(4) However, if it can be demonstrated that *E. coli* or fecal coliforms can adequately demonstrate the presence of fecal contamination in marine waters, then the *E. coli* or fecal coliform maximum limit for fresh waters may be used. The maximum geometric mean for *E. coli* is 200/100 mL; resampling should be performed when any sample exceeds 400/100 mL. When experience has shown that >90% of the fecal coliforms are *E. coli*, either fecal coliform or *E. coli* may be determined. When <90% of the fecal coliforms are *E. coli*, only *E. coli* may be determined.

(5) Designated bathing beach = 75% confidence limit (CL); moderate use = 82% CL; light use = 90% CL; infrequent use for bathing = 95% CL.

(6) The objectives apply to discrete samples from all parts of the water bodies, except from initial dilution zones of effluents. The initial dilution zone in the Kitimat River is defined as extending up to 100 m downstream from a discharge and up to 50% of the width of the river, from the surface to the bottom. Marine initial dilution zones are cylinders with a maximum 100-m radius around a discharge point, extending from the sediment to the water surface. Kitimat Harbour is also defined as an initial dilution zone.

(7) Fecal coliform criteria that currently exist will apply on an interim basis until use of the other preferred indicators is adopted.

(8) Water in bathing and swimming areas in which these levels are ordinarily exceeded should be protected against degradation in the quality from a new or increased source of pollution. Water of higher quality should be similarly protected against degradation beyond the levels mentioned.

(9) This represents the health investigation level for water in open and unenclosed bathing and swimming areas. Samples are to be taken during conditions representative of the water quality to which users are commonly exposed.

(10) The increase is over levels measured at a background site upstream from a discharge or series of discharges, and as close to them as possible, or in an unaffected part of the marine environment. The increase applies to downstream or affected levels.

(11) A 0.3°C temperature increase will be allowed when natural conditions exceed the given maximum. For purposes hereof, "t" represents the maximum permissible temperature increase measured at a dilution zone boundary, and "T" represents the background temperature as measured at a point(s) unaffected by the discharge and representative of the highest ambient water temperature in the vicinity of the discharge. This is with respect to Classes AA, A, and B waters, provided that temperature increases resulting from non-point source activities do not exceed 2.8°C.

(12) Background is defined as either the historical pre-development level, the upstream level existing at any given time, or, if necessary, the level in an adjacent, undisturbed water body with similar hydrologic and geologic characteristics.

Appendix D
A Compilation of Water Quality Guidelines for Recreation and Aesthetics: Chemical Variables

Table D-1. A Compilation of Water Quality Guidelines for Recreation and Aesthetics: Chemical Variables

Variable	Value ($\mu g \cdot L^{-1}$)	Rationale	Jurisdiction	Reference
Cadmium, total	<12	Average (1); Kitimat Arm (2)	British Columbia	Warrington 1987
	38	Maximum (1); Kitimat Arm (2)	British Columbia	Warrington 1987
General	Narrative	Toxic, radioactive, or deleterious material concentrations shall be below those that may adversely affect characteristic water uses, cause acute or chronic conditions to the aquatic biota, or adversely affect public health; these shall not be introduced above natural background levels; Classes AA, A, B, and C (3)	Washington	Washington State 1988
Nitrate	10 000	Maximum, as N; where nitrate and nitrite are present, the total nitrate plus nitrite-N should not exceed this value	British Columbia	Pommen 1989
Nitrite	1000	Maximum, as N	British Columbia	Pommen 1989
Phenols	5	Maximum; mandatory for bathing waters	Europe	Commission of the European Communities 1988
	50	Maximum; mandatory for bathing waters; no specific odour	Europe	Commission of the European Communities 1988
Surface-active substances	300	Maximum; guideline for bathing waters; lauryl sulphate	Europe	Commission of the European Communities 1988
	Narrative	No lasting foam; mandatory; bathing waters	Europe	Commission of the European Communities 1988
Toxic and deleterious substances	Narrative	Substances shall not exceed EPA "Quality Criteria for Water" as applicable to constituent; contact recreation	Alaska	Alaska Department of Environmental Quality 1989
	Narrative	Substances shall not be present that pose hazards to incidental human contact; secondary recreation	Alaska	Alaska Department of Environmental Quality 1989

(1) The average is calculated from at least five weekly samples taken in a 30-d period.

(2) The objectives apply to discrete samples from all parts of the water bodies, except from initial dilution zones of effluents. The initial dilution zone in the Kitimat River is defined as extending up to 100 m downstream from a discharge and up to 50% of the width of the river, from the surface to the bottom. Marine initial dilution zones are cylinders with a maximum 100-m radius around a discharge point, extending from the sediment to the water surface. Kitimat Harbour is also defined as an initial dilution zone.

(3) Class AA = extraordinary; water quality of this class shall markedly and uniformly exceed the requirements for all or substantially all uses
Class A = excellent; water quality of this class shall meet or exceed the requirements for all substantially all uses
Class B = good; water quality of this class shall meet or exceed the requirements for most uses
Class C = fair; water quality of this class shall meet or exceed the requirements for selected and essential uses

Appendix E
A Compilation of Water Quality Guidelines for Industrial Water Supplies: General Variables

Table E-1. A Compilation of Water Quality Guidelines for Industrial Water Supplies: General Variables

Variable	Value	Rationale	Jurisdiction	Reference
Aesthetic considerations	Narrative	Waters should be: a) free from substances that will settle to form putrescent or otherwise objectionable sludge deposits; b) free from floating debris, oil, grease, scum, foam, and other floating materials in amounts sufficient to be unsightly or otherwise objectionable; c) free from material that will produce colour, odour, turbidity, or other conditions to such a degree as to be unsightly or otherwise objectionable; Class 1, 2, and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
Chemical oxygen demand	3 $mg \cdot L^{-1}$	Maximum; indutrial water	Japan	Japan Environment Agency 1987
Colour	25 units	Maximum colour of surface waters that have been used in petroleum industry	United States	U.S. EPA 1987
	75 units	For seafood processing	Alaska	Alaska Department of Environmental Quality 1989
	360 units	Maximum colour of surface waters that have been used in pulp and paper industry	United States	U.S. EPA 1987
	500 units	Maximum colour of surface waters that have been used in chemical and allied products industries	United States	U.S. EPA 1987
	1200 units	Maximum colour of surface waters that have been used as sources of boiler make-up and cooling water	United States	U.S. EPA 1987
Dissolved oxygen	4.3 $mg \cdot L^{-1}$	Minimum; Classes 1, 2, and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	5 $mg \cdot L^{-1}$	Up to 6 consecutive hours; Classes 1, 2, and 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	5 $mg \cdot L^{-1}$	Minimum; industrial water	Japan	Japan Environment Agency 1987
	5 $mg \cdot L^{-1}$	Minimum; industrial water	Alaska	Alaska Department of Environmental Quality 1989
	9 $mg \cdot L^{-1}$	Maximum; industrial water	Alaska	Alaska Department of Environmental Quality 1989
Fecal coliforms (FC)	5 FC/100 mL	Median for molluscs held in tanks; Class 2 (1,2)	W. Australia	Western Australia Department of Conservation and Environment 1981

Table E-1. Continued

Variable	Value	Rationale	Jurisdiction	Reference
Fecal coliforms (FC)	15 FC/100 mL	80th percentile; for molluscs held in tanks; Class 2 (1,2)	W. Australia	Western Australia Department of Conservation and Environment 1981
	200 FC/100 mL	To avoid adverse effects on workers where contact with water source is probable	Alaska	Alaska Department of Environmental Quality 1989
Floating or submerged material	Narrative	Waters should not contain floating or submerged material or objects that would cause nuisance or interfere with this use; Class 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
Ionic ratio	Narrative	Ratios of major ions should not be altered such that this beneficial use is affected (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
Odour	Narrative	Waters should not contain odorous or odour-producing substances in concentrations that would cause nuisance or render them unsuitable for use; Class 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
Oil and grease	Narrative	Waters should not contain oil, grease, wax, or other similar materials in concentrations that result in a visible film or coating on the surface of the water, that cause nuisance, or that render the waters unsuitable for use; Class 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
pH units	6.5–8.5	Class 2 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	7.8–8.3	Industrial water	Japan	Japan Environment Agency 1987
	0.5 units	Maximum variation from natural levels; Class 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
Salinity	Narrative	Unnatural influences should not change the seasonal mean salinity, preferably measured over at least 5 years, by more than 0.25 standard deviations, nor change the salinity beyond the range recorded over that period; Class 2 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
Sediment	Narrative	No imposed loads that will interfere with established water supply treatment levels; aquaculture	Alaska	Alaska Department of Environmental Quality 1989
	Narrative	Below normally detectable amounts; water supply for seafood processing	Alaska	Alaska Department of Environmental Quality 1989

Table E-1. Continued

Variable	Value	Rationale	Jurisdiction	Reference
Settleable matter	Narrative	Waters should not contain settleable matter in concentrations that cause deposits that would adversely affect this beneficial use; Class 3	W. Australia	Western Australia Department of Conservation and Environment 1981
Suspended solids	160 $mg \cdot L^{-1}$	Maximum; Class 2 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	Narrative	Waters should not contain suspended matter in concentrations that would render them unsuitable for use; Class 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
Temperature	2°C	Maximum acceptable variation in the weekly average temperature due to artificial sources for waters north of latitude 27°S; Class 2 (1,3)	W. Australia	Western Australia Department of Conservation and Environment 1981
	2°C	Change from ambient conditions; Class 3 (1)	W. Australia	Western Australia Department of Conservation and Environment 1981
	4°C	Maximum acceptable variation in the weekly average temperature due to artificial sources for waters south of latitude 27°S; Class 2 (1,3)	W. Australia	Western Australia Department of Conservation and Environment 1981
	15°C	Maximum; water supply for seafood processing	Alaska	Alaska Department of Environmental Quality 1989
Turbidity	Narrative	Shall not cause detrimental effects on established levels of water supply treatment; water supply for seafood processing	Alaska	Alaska Department of Environmental Quality 1989

(1) Class 1 = food processing, washing, and cooking procedures
Class 2 = food processing, in-plant holding procedures
Class 3 = steam generation, cooling, and other processes
(2) A minimum of five samples taken over a maximum 30-d period are tested.
(3) Applicable during all seasons of the year, provided no single value exceeds, by more than 2°C, the highest summer maximum recorded over the previous 5 years, inclusive.

Appendix F
A Compilation of Water Quality Guidelines for Industrial Water Supplies: Chemical Variables

Table F-1. A Compilation of Water Quality Guidelines for Industrial Water Supplies: Chemical Variables

Variable	Value ($\mu g \cdot L^{-1}$)	Approach	Rationale	Jurisdiction	Reference
Aldrin	0.015	(1)	Maximum; class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
Ammonia	3000	(1)	6-month median; Class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
	5000	(1)	Maximum; Class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
Arsenic	40	(1)	6-month median; Class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
	500	(1)	Maximum; Class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
Azinphosmethyl	0.05	(1)	Maximum; Class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
Cadium	15	(1)	6-month median; Class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
	40	(1)	Maximum; Class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
Camphechlor	0.025	(1)	Maximum; Class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
Chemicals, other	Narrative		No chemcical, other than those naturally occurring, should be present in concentrations that would adversely affect this beneficial use; the waters should not contain any toxicant or other material that would endanger personnel; Class 3 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
Chlordane	0.02	(1)	Maximum; Class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
Chlorine, total residual	10	(1)	6-month median; Class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
	30	(1)	Maximum; Class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981

2,4-D = 2,4-dichlorophenoxyacetic acid
DDT = dichlorodiphenyltrichloroethane
PCB = polychlorinated biphenyl

Table F-1. Continued

Variable	Value ($\mu g \cdot L^{-1}$)	Approach	Rationale	Jurisdiction	Reference
Chromium, total	10	(1)	6-month median; Class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
	35	(1)	Maximum; Class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
Copper	25	(1)	6-month median; Class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
	40	(1)	Maximum; Class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
Cyanide	25	(1)	6-month median; Class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
	40	(1)	Maximum; Class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
2,4-D	20	(1)	Maximum; Class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
DDT	0.005	(1)	Maximum; Class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
Dieldrin	0.015	(1)	Maximum; Class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
Endosulfan	0.005	(1)	Maximum; Class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
Endrin	0.02	(1)	Maximum; Class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
Fluoride	10 000	(1)	Maximum; Class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
General	Narrative		Class 1 (2); where waters are to be protected for this beneficial use, the applicable criteria in respect of toxicological and radiological parameters should be those set out as desirable current criteria in the Department of Health document "Desirable Quality of Drinking Water in Australia," published by the AGPS Canberra, 1980	W. Australia	Western Australia Department of Conservation and Environment 1981
Heptachlor	0.005	(1)	Maximum; Class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
Hydrocarbons, aromatic	5	(1)	Maximum; Class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981

Table F-1. Continued

Variable	Value ($\mu g \cdot L^{-1}$)	Approach	Rationale	Jurisdiction	Reference
Hydrocarbons, total	50	(1)	Maximum; Class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
Hydrogen sulphide	10	(1)	Maximum; Class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
Lead	40	(1)	6-month median; Class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
	200	(1)	Maximum; Class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
Lindane	0.02	(1)	Maximum; Class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
Malidison	0.5	(1)	Maximum; Class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
Mercury	0.7	(1)	6-month median; Class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
	3	(1)	Maximum; Class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
Methoxychlor	0.15	(1)	Maximum; Class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
Nickel	100	(1)	6-month median; Class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
	450	(1)	Maximum; Class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
Nutrients and other biostimulants	Narrative		Added nutrients or growth stimulants should not cause excessive or nuisance algal or other plant growth; Class 3 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
Parathion	0.2	(1)	Maximum; Class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
PCBs	0.005	(1)	Maximum; Class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
Pesticides, other	Narrative		0.05 of the 96-h LC_{50}; for selected test species; Class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
Phenolic compounds	300	(1)	6-month median; Class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981

Table F-1. Continued

Variable	Value ($\mu g \cdot L^{-1}$)	Approach	Rationale	Jurisdiction	Reference
Radioactive substances	Narrative		Should not be present in concentrations that are deleterious to human, plant, animal, or aquatic life or that result in the accumulation of these substances in the food web to an extent that presents a hazard to human plant, animal, or aquatic life; Class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
	Narrative		Should not be present in concentrations that are deleterious to this beneficial use; Class 3 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
	Narrative		Should not exceed Alaska Drinking Water Standards	Alaska	Alaska Department of Environmental Quality 1989
Silver	2.25	(1)	6-month median; Class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
	10	(1)	Maximum; Class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
Surfactants	Narrative		0.05 of the 96-h LC_{50}; for the test organisms; Class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
	Narrative		Waters should not contain surfactants in quantities that give rise to foam or otherwise interfere with their use; Class 3 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
Tainting agents	Narrative		Taste- or odour-producing substances should not be present at concentrations that lead to undesirable tastes or odours in fish flesh or other edible products of aquatic origin; Class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
Zinc	100	(1)	6-month median; Class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981
	200	(1)	Maximum; Class 2 (2)	W. Australia	Western Australia Department of Conservation and Environment 1981

(1) Calculated as five times the guideline for protection of aquatic life.

(2) Class 1 = maximum protection for ecosystems and corresponds to water quality of a natural or pristine state; they should not receive any waste discharge whatsoever, nor be affected by man-made changes within the surface or ground watersheds, nor the body of water itself

Class 2 = a high level of protection such that any waste discharges or man-made changes that do occur may be readily assimilated or withstood by the system without any detectable effects on the biota or the structure of the ecosystem to which they belong

Class 3 = a minimal level of protection such that any waste discharge or man-made changes that do occur may lead to changes in the present biota but do not change the nature of the residing biota to the point at which it no longer functions as an ecosystem

Appendix G
A Compilation of Sediment Quality Guidelines for the Protection of Aquatic Life

Table G-1. A Compilation of Sediment Quality Guidelines for the Protection of Aquatic Life

Variable	Value ($\mu g \cdot g^{-1}$)*	Approach	Rationale	Jurisdiction	Reference
Acenaphthene	0.063	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	0.16	AET	Interim criterion @ 1% TOC (1)	Washington	Washington Department of Ecology 1989
	0.2	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	0.5	AET	New LAET dry weight (3)	Washington	Washington Department of Ecology 1988
	0.5	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	0.57	AET	LAET benthic community composition; 1% TOC (5)	Washington	Barrick *et al.* 1988
	0.63	AET	Maximum level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	16.5	EP	EPA chronic marine threshold @ 1% TOC	United States	Bolton *et al.* 1985
	16.5	EP	Safe level predicted from chronic water quality criterion @ 1% TOC	United States	Pavlou 1987
	23	EP	Safe level predicted from acute water quality criterion @ 1% TOC	United States	Pavlou 1987
Acenaphthylene	0.0474	SLC	National screening level concentration for marine sediments @ 1% TOC	United States	Neff *et al.* 1987
	0.064	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	0.13	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	0.64	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	0.64	AET	Maximum level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	0.66	AET	LAET benthic community composition; 1% TOC (5)	Washington	Barrick *et al.* 1988
	1.3	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988
	6	EP	EPA chronic marine threshold @ 1% TOC	United States	Bolton *et al.* 1985
	0.66	AET	Interim criterion @ 1% TOC (1)	Washington	Washington Department of Ecology 1989
Aldrin	0.0043	EP	99th percentile chronic marine permissible concentration @ 1% TOC (6)	United States	Pavlou *et al.* 1987

ACR = acute to chronic ratio
AET = apparent effects threshold
2,4-D = 2,4-dichlorophenoxyacetic acid
DDD = dichlorodiphenyldichloroethane
DDE = dichlorodiphenyldichloroethylene
DDT = dichlorodiphenyltrichloroethane
EP = equilibrium partitioning
EPA = Environmental Protection Agency
FDA = Food and Drug Administration
IUPAC = International Union of Pure and Applied Chemistry
LAET = lowest apparent effects threshold
NOEC = no-observed-effects concentration
PAH = polycyclic aromatic hydrocarbon
PCB = polychlorinated biphenyl
SB = sediment background
SLC = screening level concentration
SQT = sediment quality triad
TOC = total organic carbon
2,4,5-T = 2,4,5-trichlorophenoxyacetic acid

*Unless otherwise indicated

Table G-1. Continued

Variable	Value ($\mu g \cdot g^{-1}$)*	Approach	Rationale	Jurisdiction	Reference
Aldrin	0.0052	EP	Safe level predicted from acute water quality criterion @ 1% TOC	United States	Pavlou 1987
	0.005 25	EP	EPA chronic marine threshold @ 1% TOC	United States	Bolton *et al.* 1985
	0.0084	EP	95th percentile chronic marine permissible concentration @ 1% TOC (6)	United States	Pavlou *et al.* 1987
	0.02	SB	U.S. Geological Survey sediment alert level (7)	United States	Pavlou and Weston 1983
Aniline	0.002 48	EP	Interim mean criterion @ 1% TOC; based on Final Chronic Value (8)	United States	U.S. EPA 1988
Anthracene	0.13	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	0.163	SLC	National screening level concentration for marine sediments @ 1% TOC	United States	Neff *et al.* 1987
	0.19	EP	99th percentile chronic marine permissible concentration @ 1% TOC (6)	United States	Pavlou *et al.* 1987
	0.38	EP	95th percentile chronic marine permissible concentration @ 1% TOC (6)	United States	Pavlou *et al.* 1987
	0.96	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988
	1.3	AET	Maximum level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	1.3	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	1.3	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	2.2	AET	Interim criterion @ 1% TOC (1)	Washington	Washington Department of Ecology 1989
	2.2	AET	LAET benthic community composition; 1% TOC (5)	Washington	Barrick *et al.* 1988
	11	EP	EPA chronic marine threshold @ 1% TOC	United States	Bolton *et al.* 1985
Antimony	2.6	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	3.2	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	20	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	26	AET	Maximum level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	150	AET	LAET benthic community composition; dry weight (5)	Washington	Barrick *et al.* 1988
	150	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988

Table G-1. Continued

Variable	Value ($\mu g \cdot g^{-1}$)*	Approach	Rationale	Jurisdiction	Reference
Antimony	500	SB	EPA Region VI proposed guideline for open-water disposal	United States	Pavlou and Weston 1983
Arsenic	57	AET	Interim criterion; dry weight (1)	Washington	Washington Department of Ecology 1989
	3	SB	EPA Region V guideline for pollutional classification of sediments (9)	United States	Pavlou and Weston 1983
	5	SB	EPA Region VI proposed guideline for open-water disposal	United States	Pavlou and Weston 1983
	8	SB	Ontario Ministry of the Environment dredge spoil guideline for open-water disposal	Ontario	Fitchko 1989
	8.25	EP	EPA chronic marine threshold @ 1% TOC	United States	Bolton *et al.* 1985
	16	EP	EPA acute marine threshold @ 1% TOC	United States	Lyman *et al.* 1987
	35	SB	Recommended target value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989
	40		Potential adverse effects on water quality (10)	Oregon	Oregon Department of Environmental Quality 1989a
	45	SB	Recommended directive value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989
	57	AET	LAET benthic community composition; dry weight (5)	Washington	Barrick *et al.* 1988
	57	AET	ACR NOEC; dry weight (2,11)	Washington	Washington Department of Ecology 1988
	57	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988
	70	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	85	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	100	SB	Recommended limit value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989
	200	SB	U.S. Geological Survey sediment alert level (7)	United States	Pavlou and Weston 1983
	700	AET	Maximum level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
Barium	20	SB	EPA Region V guideline for pollutional classification of sediments (9)	United States	Pavlou and Weston 1983
	2000	SB	U.S. Geological Survey sediment alert level (7)	United States	Pavlou and Weston 1983
Benzene	0.34	EP	EPA chronic marine threshold @ 1% TOC	United States	Bolton *et al.* 1985
Benzo(a)anthracene	0.261	SLC	National screening level concentration for marine sediments @ 1% TOC	United States	Neff *et al.* 1986

Table G-1. Continued

Variable	Value ($\mu g \cdot g^{-1}$)*	Approach	Rationale	Jurisdiction	Reference
Benzo(a)anthracene	0.261	SLC	National screening level concentration for marine sediments @ 1% TOC; recalculated	United States	Neff *et al.* 1987
	0.45	AET	Screening level for dredged disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	0.51	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	1.1	AET	Interim criterion @ 1% TOC (1)	Washington	Washington Department of Ecology 1989
	1.3	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988
	1.6	EP	99th percentile chronic marine permissible concentration @ 1% TOC (6)	United States	Pavlou *et al.* 1987
	4.5	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	4.5	AET	Maximum level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	6.5	AET	LAET benthic community composition; 1% TOC (5)	Washington	Barrick *et al.* 1988
	13.17	EP	Interim mean criterion @ 1% TOC	United States	U.S. EPA 1988
	21	EP	95th percentile chronic marine permissible concentration @ 1% TOC (6)	United States	Pavlou *et al.* 1987
	55	EP	Safe level predicted from acute water quality criterion @ 1% TOC	United States	Pavlou 1987
	55	EP	EPA chronic marine threshold @ 1% TOC	United States	Bolton *et al.* 1985
	55	EP	EPA acute marine threshold @ 1% TOC	United States	Lyman *et al.* 1987
Benzo(a)pyrene	0.2	SB	Recommended target value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989
	0.36	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	0.396	SLC	National screening level concentration for marine sediments @ 1% TOC	United States	Neff *et al.* 1986
	0.397	SLC	National screening level concentration for marine sediments @ 1% TOC; recalculated	United States	Neff *et al.* 1987
	0.68	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	0.75	SB	Recommended directive value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989
	0.99	AET	Interim criterion @ 1% TOC (1)	Washington	Washington Department of Ecology 1989
	1.6	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988

Table G-1. Continued

Variable	Value ($\mu g \cdot g^{-1}$)*	Approach	Rationale	Jurisdiction	Reference
Benzo(a)pyrene	3.5	SB	Recommended limit value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989
	6.8	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	6.8	AET	Maximum level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	10.63	EP	Interim mean criterion @ 1% TOC	United States	U.S. EPA 1988
	>13	AET	LAET benthic community composition; 1% TOC (5)	Washington	Barrick *et al.* 1988
	18	EP	99th percentile chronic marine permissible concentration @ 1% TOC (6)	United States	Pavlou *et al.* 1987
	45	EP	95th percentile chronic marine permissible concentration @ 1% TOC (6)	United States	Pavlou *et al.* 1987
	450	EP	Safe level predicted from acute water quality criterion @ 1% TOC	United States	Pavlou 1987
	450	EP	EPA chronic marine threshold @ 1% TOC	United States	Bolton *et al.* 1985
	450	EP	EPA acute marine threshold @ 1% TOC	United States	Lyman *et al.* 1987
Benzofluoranthenes	0.8	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	0.99	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	2.3	AET	Interim criterion @ 1% TOC (1); sum of "b," "j," and "k" isomers	Washington	Washington Department of Ecology 1989
	3.2	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988
	8	AET	Maximum level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	8	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	15	AET	LAET benthic community composition; 1% TOC (5)	Washington	Barrick *et al.* 1988
Benzo(a)fluoranthene	0.55	SB	Recommended target value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989
	0.75	SB	Recommended directive value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989
	3.5	SB	Recommended limit value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989
Benzo(k)fluoranthene	0.55	SB	Recommended target value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989

Table G-1. Continued

Variable	Value ($\mu g \cdot g^{-1}$)*	Approach	Rationale	Jurisdiction	Reference
Benzo(k)fluoranthene	0.75	SB	Recommended directive value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989
	3.5	SB	Recommended limit value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989
	1250	EP	EPA chronic marine threshold @ 1% TOC	United States	Bolton *et al.* 1985
Benzo(g,h,i)perylene	0.2	SB	Recommended target value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989
	0.26	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	0.31	AET	Interim criterion @ 1% TOC (1)	Washington	Washington Department of Ecology 1989
	0.54	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	0.67	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988
	0.75	SB	Recommended directive value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989
	3.5	SB	Recommended limit value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989
	5.4	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	5.4	AET	Maximum level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	>12	AET	LAET benthic community composition; 1% TOC (5)	Washington	Barrick *et al.* 1988
Benzoic acid	0.65	AET	Interim criterion; dry weight (1)	Washington	Washington Department of Ecology 1989
	0.076	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	0.216	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	0.65	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	0.65	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988
	0.69	AET	Maximum level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	>1.7	AET	LAET benthic community composition; 1% TOC (5)	Washington	Barrick *et al.* 1988
Benzyl alcohol	0.057	AET	Interim criterion; dry weight (1)	Washington	Washington Department of Ecology 1989
	0.01	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989

Table G-1. Continued

Variable	Value ($\mu g \cdot g^{-1}$)*	Approach	Rationale	Jurisdiction	Reference
Benzyl alcohol	0.057	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988
	0.073	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	0.073	AET	Maximum level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	0.087	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	>0.73	AET	LAET benthic community composition; 1% TOC (5)	Washington	Barrick *et al.* 1988
Beryllium	200	SB	U.S. Geological Survey sediment alert level (7)	United States	Pavlou and Weston 1983
Bis(2-ethylhexyl) phthalate	0.19	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	0.47	AET	Interim criterion @ 1% TOC (1)	Washington	Washington Department of Ecology 1989
	0.6	AET	LAET benthic community composition; 1% TOC (5)	Washington	Barrick *et al.* 1988
	1.3	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988
	1.9	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	3.1	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	31	AET	Maximum level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
Butylbenzyl phthalate	0.049	AET	Interim criterion @ 1% TOC (1)	Washington	Washington Department of Ecology 1989
	0.063	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988
	0.09	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	0.47	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	0.47	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	0.64	AET	LAET benthic community composition; 1% TOC (5)	Washington	Barrick *et al.* 1988
	47	AET	Maximum level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	55	EP	EPA chronic marine threshold @ 1% TOC	United States	Bolton *et al.* 1985
Cadmium	0.6		Includes cadmium compounds; in the solid phase of a waste	Canada	Ocean Dumping Regulations 1988b
	0.96	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	0.96	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1889

Table G-1. Continued

Variable	Value ($\mu g \cdot g^{-1}$)*	Approach	Rationale	Jurisdiction	Reference
Cadmium	1	SB	Ontario Ministry of the Environment dredge spoil guideline for open-water disposal	Ontario	Fitchko 1989
	1		Potential adverse effects on water quality (10)	Oregon	Oregon Department of Environmental Quality 1989a
	1.4	SB	Recommended target value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989
	2	SB	EPA Region VI proposed guideline for open-water disposal	United States	Pavlou and Weston 1983
	3		Includes cadmium compounds; in the liquid phase of a waste	Canada	Ocean Dumping Regulations 1988b
	5.1	AET	LAET benthic community composition; dry weight (5)	Washington	Barrick *et al.* 1988
	5.1	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988
	5.8	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	6.0	SB	EPA Region V guideline for pollutional classification of sediments (9)	United States	Pavlou and Weston 1983
	7.5	SB	Recommended directive value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989
	7.75	EP	EPA chronic marine threshold @ 1% TOC	United States	Bolton *et al.* 1985
	9.6	AET	Maximum level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	20	SB	U.S. Geological Survey sediment alert level (7)	...ed States	Pavlou and Weston 1983
	24	EP	EPA acute marine threshold @ 1% TOC	...ted States	Lyman *et al.* 1987
	30	SB	Recommended limit value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989
	Narrative	SB	The concentrations in sediments must not increase significantly with time (12)	Europe	Commission of the European Communities 1988
Chlordane	0.0003	EP	99th percentile chronic marine permissible concentration @ 1% TOC (13)	United States	Pavlou *et al.* 1987
	0.0006	EP	95th percentile chronic marine permissible concentration @ 1% TOC (13)	United States	Pavlou *et al.* 1987
	0.02	SB	U.S. Geological Survey sediment alert level (7)	United States	Pavlou and Weston 1983
Chlorophenols	0.01		Sturgeon and Roberts Banks; the Fraser River, including the Main Stem, the North, Middle, and Main arms; dry weight; maximum in bottom surface sediments (14)	British Columbia	Swain and Holms 1985
Chlorpyrifos	0.0044	EP	Interim mean criterion @ 1% TOC; based on Final Chronic Value (8)	United States	Environmental Protection Agency 1988

Table G-1. Continued

Variable	Value ($\mu g \cdot g^{-1}$)*	Approach	Rationale	Jurisdiction	Reference
Chromium	25	SB	Ontario Ministry of the Environment dredge spoil guideline for open-water disposal	Ontario	Fitchko 1989
	25	SB	EPA Region V guideline for pollutional classification of sediments (9)	United States	Pavlou and Weston 1983
	27	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	100	SB	EPA Region VI proposed guideline for open-water disposal	United States	Pavlou and Weston 1983
	115	SB	Recommended target value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989
	155	SB	Recommended directive value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989
	20–300		Potential adverse effects on water quality (10)	Oregon	Oregon Department of Environmental Quality 1989a
	200	SB	U.S. Geological Survey sediment alert level (7)	United States	Pavlou and Weston 1983
	260	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988
	260	AET	LAET benthic community composition; dry weight (5)	Washington	Barrick *et al.* 1988
	600	SB	Recommended limit value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989
Chrysene	0.384	SLC	National screening level concentration for marine sediments @ 1% TOC	United States	Neff *et al.* 1986
	0.384	SLC	National screening level concentration for marine sediments @ 1% TOC; recalculated	United States	Neff *et al.* 1987
	0.67	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	0.92	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	1.1	AET	Interim criterion @ 1% TOC (1)	Washington	Washington Department of Ecology 1989
	1.2	EP	99th percentile chronic marine permissible concentration @ 1% TOC (6)	United States	Pavlou *et al.* 1987
	1.4	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988
	4.4	EP	95th percentile chronic marine permissible concentration @ 1% TOC (6)	United States	Pavlou *et al.* 1987
	6.7	AET	Maximum level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	6.7	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986

Table G-1. Continued

Variable	Value ($\mu g \cdot g^{-1}$)*	Approach	Rationale	Jurisdiction	Reference
Chrysene	8.5	AET	LAET benthic community composition; 1% TOC (5)	Washington	Barrick *et al.* 1988
	115	EP	Safe level predicted from acute water quality criterion @ 1% TOC	United States	Pavlou 1987
	115	EP	EPA chronic marine threshold @ 1% TOC	United States	Bolton *et al.* 1985
	115	EP	EPA acute marine threshold @ 1% TOC	United States	Lyman *et al.* 1987
Copper	25	SB	Ontario Ministry of the Environment dredge spoil guideline for open-water disposal	Ontario	Fitchko 1989
	25	SB	EPA Region V guideline for pollutional classification of sediments (9)	United States	Pavlou and Weston 1983
	34	EP	EPA chronic marine threshold @ 1% TOC	United States	Bolton *et al.* 1985
	35	SB	Recommended target value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989
	50	SB	EPA Region VI proposed guideline for open-water disposal	United States	Pavlou and Weston 1983
	50		Potential adverse effects on water quality (10)	Oregon	Oregon Department of Environmental Quality 1989a
	54	EP	EPA acute marine threshold @ 1% TOC	United States	Lyman *et al.* 1987
	81	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	90	SB	Recommended directive value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989
	130	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	310	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	390	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988
	400	SB	Recommended limit value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989
	530	AET	LAET benthic community composition; dry weight (5)	Washington	Barrick *et al.* 1988
	810	AET	Maximum level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	2000	SB	U.S. Geological Survey sediment alert level (7)	United States	Pavlou and Weston 1983
Crude oil	10		N-hexane-soluble substances; includes crude oil and its wastes, refined petroleum products, petroleum distillate residues, and any mixtures containing any of these substances	Canada	Ocean Dumping Regulations 1988b

Table G-1. Continued

Variable	Value ($\mu g \cdot g^{-1}$)*	Approach	Rationale	Jurisdiction	Reference
Cyanide	0.025	EP	EPA chronic marine threshold @ 1% TOC	United States	Bolton *et al.* 1985
	0.1	SB	Ontario Ministry of the Environment dredge spoil guideline for open-water disposal	Ontario	Fitchko 1989
	0.1	SB	EPA Region V guideline for pollutional classification of sediments (9)	United States	Pavlou and Weston 1983
	100	SB	U.S. Geological Survey sediment alert level (7)	United States	Pavlou and Weston 1983
2,4-D	0.02	SB	U.S. Geological Survey sediment alert level (7)	United States	Pavlou and Weston 1983
DDD	0.002	AET	LAET benthic comn.unity composition; dry weight (4)	Washington	Beller *et al.* 1986
	0.006	EP	99th percentile chronic marine permissible concentration @ 1% TOC (6)	United States	Pavlou *et al.* 1987
	0.01	AET	LAET benthic community composition; 1% TOC (5)	Washington	Barrick *et al.* 1988
	0.022	EP	95th percentile chronic marine permissible concentration @ 1% TOC (6)	United States	Pavlou *et al.* 1987
	3.25	EP	Safe level predicted from acute water quality criterion @ 1% TOC	United States	Pavlou 1987
	3.25	EP	EPA chronic marine threshold @ 1% TOC	United States	Bolton *et al.* 1985
	3.25	EP	EPA acute marine threshold @ 1% TOC	United States	Lyman *et al.* 1987
DDE	0.0031	AET	LAET benthic community composition; 1% TOC (5)	Washington	Barrick *et al.* 1988
	0.009	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	0.027	EP	99th percentile chronic marine permissible concentration @ 1% TOC (6)	United States	Pavlou *et al.* 1987
	0.06	EP	95th percentile chronic marine permissible concentration @ 1% TOC (6)	United States	Pavlou *et al.* 1987
	7	EP	EPA chronic marine threshold @ 1% TOC	United States	Bolton *et al.* 1985
	7	EP	EPA acute marine threshold @ 1% TOC	United States	Lyman *et al.* 1987
	7	EP	Safe level predicted from acute water quality criterion @ 1% TOC	United States	Pavlou 1987
p,p'-DDT	0.0004	EP	99th percentile chronic marine permissible concentration @ 1% TOC (13)	United States	Pavlou *et al.* 1987
	0.0007	EP	95th percentile chronic marine permissible concentration @ 1% TOC (13)	United States	Pavlou *et al.* 1987

Table G-1. Continued

Variable	Value ($\mu g \cdot g^{-1}$)*	Approach	Rationale	Jurisdiction	Reference
p,p'-DDT	0.0015	EP	EPA chronic marine threshold @ 1% TOC	United States	Bolton *et al.* 1985
	0.0016	EP	Safe level predicted from chronic water quality criterion @ 1% TOC	United States	Pavlou 1987
	0.008 28	EP	Interim mean criterion @ 1% TOC; based on Final Residue Value (8)	United States	U.S. EPA 1988
	0.011	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	0.02	SB	U.S. Geological Survey sediment alert level (7)	United States	Pavlou and Weston 1983
	0.033	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	0.037	AET	LAET benthic community composition; 1% TOC (5)	Washington	Barrick *et al.* 1988
	0.059	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988
	0.2	EP	Includes DDD and DDE; levels exceeding this guideline will be regarded as having potential for adversely affecting water quality for human and/or wildlife consumption	Oregon	Oregon Department of Environmental Quality 1989a
	0.21	EP	Safe level predicted from acute water quality criterion @ 1% TOC	United States	Pavlou 1987
	0.21	EP	EPA acute marine threshold @ 1% TOC	United States	Lyman *et al.* 1987
	0.428	SLC	National screening level concentration for marine sediments @ 1% TOC	United States	Neff *et al.* 1986
	0.505	SLC	National screening level concentration for marine sediments @ 1% TOC; recalculated	United States	Neff *et al.* 1987
	Narrative	SB	The concentration of DDT in sediments must not increase significantly with time (15)	Europe	Commission of the European Communities 1988
Dibenzo(a,h)-anthracene	0.097	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	0.12	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	0.23	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988
	0.12	AET	Interim criterion @ 1% TOC (1)	Washington	Washington Department of Ecology 1989
	0.89	AET	LAET benthic community composition; 1% TOC (5)	Washington	Barrick *et al.* 1988
	1.2	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	1.2	AET	Maximum level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989

Table G-1. Continued

Variable	Value ($\mu g \cdot g^{-1}$)*	Approach	Rationale	Jurisdiction	Reference
Dibenzo(a,h)-anthracene	12	EP	99th percentile chronic marine permissible concentration @ 1% TOC (6)	United States	Pavlou *et al.* 1987
	35	EP	95th percentile chronic marine permissible concentration @ 1% TOC (6)	United States	Pavlou *et al.* 1987
	240	EP	Safe level predicted from acute water quality criterion @ 1% TOC	United States	Pavlou 1987
Dibenzofuran	0.054	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	0.15	AET	Interim criterion @ 1% TOC (1)	Washington	Washington Department of Ecology 1989
	0.17	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	0.54	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988
	0.54	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	0.54	AET	Maximum level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	0.58	AET	LAET benthic community composition; 1% TOC (5)	Washington	Barrick *et al.* 1988
Dichlorobenzene	0.7	EP	EPA chronic marine threshold @ 1% TOC	United States	Bolton *et al.* 1985
1,2-Dichlorobenzene	0.019	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	0.019	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	0.023	AET	Interim criterion @ 1% TOC (1)	Washington	Washington Department of Ecology 1989
	0.023	AET	LAET benthic community composition; 1% TOC (5)	Washington	Barrick *et al.* 1988
	0.035	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988
	0.05	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	0.19	AET	Maximum level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
1,3-Dichlorobenzene	0.017	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	>0.15	AET	LAET benthic community composition; 1% TOC (5)	Washington	Barrick *et al.* 1988
	0.17	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	0.17	AET	New LAET; dry weight (3,16)	Washington	Washington Department of Ecology 1988
	>0.17	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	NV (17)	AET	New LAET	Washington	Washington Department of Ecology 1989

Table G-1. Continued

Variable	Value ($\mu g \cdot g^{-1}$)*	Approach	Rationale	Jurisdiction	Reference
1,4-Dichlorobenzene	0.012	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	0.026	AET	Screening level for dredge disposal	Washington	Puget S and Dredged Disposal Analysis 1989
	0.031	AET	Interim criterion @ 1% TOC (1)	Washington	Washington Department of Ecology 1989
	0.11	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988
	0.12	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	0.16	AET	LAET benthic community composition; 1% TOC (5)	Washington	Barrick *et al.* 1988
	0.26	AET	Maximum level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
Dieldrin	0.000 01	EP	99th percentile chronic marine permissible concentration @ 1% TOC (13)	United States	Pavlou *et al.* 1987
	0.000 02	EP	95th percentile chronic marine permissible concentration @ 1% TOC (13)	United States	Pavlou *et al.* 1987
	0.0013	EP	Interim mean criterion @ 1% TOC; based on Final Residue Value (8)	United States	U.S. EPA 1988
	0.02	SB	U.S. Geological Survey sediment alert level (7)	United States	Pavlou and Weston 1983
	0.0577	EP	Interim mean criterion @ 1% TOC; based on Final Chronic Value (8)	United States	U.S. EPA 1988
Diethyl phthalate	0.02	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	0.097	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	0.097	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	0.2	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988
	0.32	EP	EPA chronic marine threshold @ 1% TOC	United States	Bolton *et al.* 1985
	0.61	AET	LAET benthic community composition; 1% TOC (5)	Washington	Barrick *et al.* 1988
	0.61	AET	Interim criterion @ 1% TOC (1)	Washington	Washington Department of Ecology 1989
2,4-Dimethyl phenol	0.01	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	0.021	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	0.026	AET	LAET benthic community composition; 1% TOC (5)	Washington	Barrick *et al.* 1988

Table G-1. Continued

Variable	Value ($\mu g \cdot g^{-1}$)*	Approach	Rationale	Jurisdiction	Reference
2,4-Dimethyl phenol	0.029	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	0.029	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988
	0.05	AET	Maximum level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
Dimethyl phthalate	0.016	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	0.071	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988
	0.16	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	0.16	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	0.49	EP	EPA chronic marine threshold @ 1% TOC	United States	Bolton *et al.* 1985
	0.53	AET	LAET benthic community composition; 1% TOC (5)	Washington	Barrick *et al.* 1988
	0.53	AET	Interim criterion @ 1% TOC (1)	Washington	Washington Department of Ecology 1989
Di-n-butyl phthalate	0.14	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	1.4	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988
	1.4	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	2.2	AET	Interim criterion @ 1% TOC (1)	Washington	Washington Department of Ecology 1989
	>5.1	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	17	AET	LAET benthic community composition; 1% TOC (5)	Washington	Barrick *et al.* 1988
	500	EP	EPA chronic marine threshold @ 1% TOC	United States	Bolton *et al.* 1985
Dinitrotoluene	0.22	EP	EPA chronic marine threshold @ 1% TOC	United States	Bolton *et al.* 1985
Di-n-octyl phthalate	0.58	AET	Interim criterion @ 1% TOC (1)	Washington	Washington Department of Ecology 1989
	0.62	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	1.1	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988
	45	AET	LAET benthic community composition; 1% TOC (5)	Washington	Barrick *et al.* 1988
	69	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	>69	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986

Table G-1. Continued

Variable	Value ($\mu g \cdot g^{-1}$)*	Approach	Rationale	Jurisdiction	Reference
Endrin	0.000 01	EP	99th percentile chronic marine permissible concentration @ 1% TOC (13)	United States	Pavlou *et al.* 1987
	0.000 02	EP	95th percentile chronic marine permissible concentration @ 1% TOC (13)	United States	Pavlou *et al.* 1987
	0.000 53	EP	Interim mean criterion @ 1% TOC; based on Final Residue Value (8)	United States	U.S. EPA 1988
	0.002 15	EP	Interim mean criterion @ 1% TOC; based on Final Chronic Value (8)	United States	U.S. EPA 1988
	0.02	SB	U.S. Geological Survey sediment alert level (7)	United States	Pavlou and Weston 1983
Ethylbenzene	0.0037	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	0.01	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988
	0.01	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	0.037	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	>0.038	AET	LAET benthic community composition; 1% TOC (5)	Washington	Barrick *et al.* 1988
	0.05	AET	Maximum level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	1.4	EP	EPA chronic marine threshold @ 1% TOC	United States	Bolton *et al.* 1985
	NV (17)	AET		Washington	Washington Department of Ecology 1989
Extractable organochlorines (EOCl)	5.5	SB	Recommended target value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989
	7	SB	Recommended directive value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989
	20	SB	Recommended limit value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989
Fluoranthene	0.432	SLC	National screening level concentration for marine sediments @ 1% TOC	United States	Neff *et al.* 1986
	0.63	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	0.644	SLC	National screening level concentration for marine sediments @ 1% TOC; recalculated	United States	Neff *et al.* 1987
	1.2	SB	Recommended target value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989

Table G-1. Continued

Variable	Value ($\mu g \cdot g^{-1}$)*	Approach	Rationale	Jurisdiction	Reference
Fluoranthene	1.6	AET	Interim criterion @ 1% TOC (1)	Washington	Washington Department of Ecology 1989
	1.6	EP	99th percentile chronic marine permissible concentration @ 1% TOC (13)	United States	Pavlou *et al.* 1987
	2	SB	Recommended directive value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989
	2.5	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988
	3.1	EP	95th percentile chronic marine permissible concentration @ 1% TOC (13)	United States	Pavlou *et al.* 1987
	3.5	SB	Recommended limit value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989
	3.6	EP	Safe level predicted from chronic water quality criterion @ 1% TOC	United States	Pavlou 1987
	4.17	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	6.3	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	6.3	AET	Maximum level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	9	EP	Safe level predicted from acute water quality criterion @ 1% TOC	United States	Pavlou 1987
	9	EP	EPA acute marine threshold @ 1% TOC	United States	Lyman *et al.* 1987
	12	AET	LAET benthic community composition; 1% TOC (5)	Washington	Barrick *et al.* 1988
	18.83	EP	Interim mean criterion @ 1% TOC	United States	U.S. EPA 1988
Fluorene	0.059	EP	99th percentile chronic marine permissible concentration @ 1% TOC (6)	United States	Pavlou *et al.* 1987
	0.064	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	0.101	SLC	National screening level concentration for marine sediments @ 1% TOC	United States	Neff *et al.* 1987
	0.16	EP	95th percentile chronic marine permissible concentration @ 1% TOC (6)	United States	Pavlou *et al.* 1987
	0.23	AET	Interim criterion @ 1% TOC (1)	Washington	Washington Department of Ecology 1989
	0.36	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	0.54	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988

Table G-1. Continued

Variable	Value ($\mu g \cdot g^{-1}$)*	Approach	Rationale	Jurisdiction	Reference
Fluorene	0.64	AET	Maximum level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	0.64	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	0.79	AET	LAET benthic community composition; 1% TOC (5)	Washington	Barrick *et al.* 1988
	7	EP	Safe level predicted from acute water quality criterion @ 1% TOC	United States	Pavlou 1987
	7	EP	EPA chronic marine threshold @ 1% TOC	United States	Bolton *et al.* 1985
Heptachlor	0.000 04	EP	99th percentile chronic marine permissible concentration @ 1% TOC (13)	United States	Pavlou *et al.* 1987
	0.000 06	EP	95th percentile chronic marine permissible concentration @ 1% TOC (13)	United States	Pavlou *et al.* 1987
	0.001 04	EP	Interim mean criterion; 1% TOC; based on Final Residue Value (8)	United States	U.S. EPA 1988
	0.02	SB	U.S. Geological Survey sediment alert level (7)	United States	Pavlou and Weston 1983
Hexachlorobenzene	0.0038	AET	LAET benthic community composition; 1% TOC (5)	Washington	Barrick *et al.* 1988
	0.0038	AET	Interim criterion @ 1% TOC (1)	Washington	Washington Department of Ecology 1989
	0.022	AET	ACR NOEC; dry weight (2,11)	Washington	Washington Department of Ecology 1988
	0.022	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988
	0.023	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	0.23	AET	Maximum level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	0.23	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
Hexachlorobutadiene	0.011	AET	ACR NOEC; dry weight (2,11)	Washington	Washington Department of Ecology 1988
	0.011	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988
	0.029	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	0.039	AET	Interim criterion @ 1% TOC (1)	Washington	Washington Department of Ecology 1989
	0.069	AET	LAET benthic community composition; 1% TOC (5)	Washington	Barrick *et al.* 1988
	0.27	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	0.29	AET	Maximum level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	0.32	EP	EPA chronic marine threshold @ 1% TOC	United States	Bolton *et al.* 1985

Table G-1. Continued

Variable	Value ($\mu g \cdot g^{-1}$)*	Approach	Rationale	Jurisdiction	Reference
Hexachlorocyclo-hexane (Lindane)	0.001 57	EP	EPA interim criterion @ 1% TOC	United States	U.S. EPA 1988
	0.003	EP	EPA chronic marine threshold @ 1% TOC	United States	Bolton *et al.* 1985
	0.02	SB	U.S. Geological Survey sediment alert level (7)	United States	Pavlou and Weston 1983
	Narrative	SB	Lindane and its isomers; the total concentration in molluscs, fish and/or shellfish must not increase significantly with time (12)	Europe	Commission of the European Communities 1988
Hexachloroethane	1.4	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	14	AET	Maximum level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	3.6	EP	EPA chronic marine threshold @ 1% TOC	United States	Bolton *et al.* 1985
Indeno(1,2,3-c,d)-pyrene	0.069	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	0.18	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	0.2	SB	Recommended target value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989
	0.34	AET	Interim criterion @ 1% TOC (1)	Washington	Washington Department of Ecology 1989
	0.6	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988
	0.75	SB	Recommended directive value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989
	3.5	SB	Recommended limit value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989
	>5.2	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	5.25	AET	Maximum level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	9	AET	LAET benthic community composition; 1% TOC (5)	Washington	Barrick *et al.* 1988
	6000	EP	EPA chronic marine threshold @ 1% TOC	United States	Bolton *et al.* 1985
Iron	10 000	SB	Ontario Ministry of the Environment dredge spoil guideline for open-water disposal	Ontario	Fitchko 1989
	17 000	SB	EPA Region V guideline for pollutional classification of sediments (9)	United States	Pavlou and Weston 1983
Isophorone	2.4	EP	EPA chronic marine threshold @ 1% TOC	United States	Bolton *et al.* 1985

Table G-1. Continued

Variable	Value ($\mu g \cdot g^{-1}$)*	Approach	Rationale	Jurisdiction	Reference
Lead	33	EP	EPA chronic marine threshold @ 1% TOC	United States	Bolton *et al.* 1985
	40		Potential adverse effects on water quality (10)	Oregon	Oregon Department of Environmental Quality 1989a
	40	SB	EPA Region V guideline for pollutional classification of sediments (9)	United States	Pavlou and Weston 1983
	50	SB	EPA Region VI proposed guideline for open-water disposal	United States	Pavlou and Weston 1983
	50	SB	Ontario Ministry of the Environment dredge spoil guideline for open-water disposal	Ontario	Fitchko 1989
	50	SQT	No or minimal biological effects	United States	Chapman 1986
	50–130	SQT	Range of uncertain effects	United States	Chapman 1986
	66	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	66	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	70	SB	Recommended target value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989
	130	SQT	Major biological effects	United States	Chapman 1986
	160	SB	Recommended directive value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989
	300	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	450	AET	LAET benthic community composition; dry weight (5)	Washington	Barrick *et al.* 1988
	450	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988
	500	SB	U.S. Geological Survey sediment alert level (7)	United States	Pavlou and Weston 1983
	660	AET	Maximum level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	700	SB	Recommended limit value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989
	840	EP	EPA acute marine threshold @ 1% TOC	United States	Lyman *et al.* 1987
Malathion	0.02	SB	U.S. Geological Survey sediment alert level (7)	United States	Pavlou and Weston 1983
Manganese	300	SB	EPA Region V guideline for pollutional classification of sediments (9)	United States	Pavlou and Weston 1983
Mercury	0.0075	EP	EPA chronic marine threshold @ 1% TOC	United States	Bolton *et al.* 1985

Table G-1. Continued

Variable	Value ($\mu g \cdot g^{-1}$)*	Approach	Rationale	Jurisdiction	Reference
Mercury	0.15	EP	EPA acute marine threshold @ 1% TOC	United States	Lyman *et al.* 1987
	0.15		Potential adverse effects on water quality (10)	Oregon	Oregon Department of Environmental Quality 1989a
	0.2	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	0.21	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	0.3	SB	Ontario Ministry of the Environment dredge spoil guideline for open water disposal	Ontario	Fitchko 1989
	0.41	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988
	0.5	SB	Recommended target value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989
	0.75		Includes mercury compounds; in the solid phase of a waste	Canada	Ocean Dumping Regulations 1988b
	0.8	EP	EPA chronic marine threshold; not corrected for organic carbon	United States	Bolton *et al.* 1985
	0.88	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	1	SB	EPA Region V guideline for pollutional classification of sediments (9)	United States	Pavlou and Weston 1983
	1	SB	EPA Region VI proposed guideline for open-water disposal	United States	Pavlou and Weston 1983
	1.5		Includes mercury compounds; in the liquid phase of a waste	Canada	Ocean Dumping Regulations 1988b
	1.6	SB	Recommended directive value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989
	2	AET	Maximum level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	2.1	AET	LAET benthic community composition; dry weight (5)	Washington	Barrick *et al.* 1988
	15	SB	Recommended limit value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989
	20	SB	U.S. Geological Survey sediment alert level (7)	United States	Pavlou and Weston 1983
	Narrative		The concentration of mercury in sediments must not increase significantly with time (12)	Europe	Commission of the European Communities 1988
	Narrative		C=0.18(H/J)(1/S); provisional removal standard; H is the average tide difference in meters, J is the release rate of mercury, S is the safety factor (18)	Japan	Japan Environment Agency 1987
Methoxychlor	0.02	SB	U.S. Geological Survey sediment alert level (7)	United States	Pavlou and Weston 1983

Table G-1. Continued

Variable	Value ($\mu g \cdot g^{-1}$)*	Approach	Rationale	Jurisdiction	Reference
Methyl chloride	0.48	EP	EPA chronic marine threshold @ 1% TOC	United States	Bolton *et al.* 1985
Methylene chloride	0.5	EP	EPA chronic marine threshold @ 1% TOC	United States	Bolton *et al.* 1985
2-Methylnaphthalene	0.067	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	0.19	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	0.38	AET	Interim criterion @ 1% TOC (1)	Washington	Washington Department of Ecology 1989
	0.67	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988
	0.67	AET	Maximum level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	0.67	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	0.64	AET	LAET benthic community composition; 1% TOC (5)	Washington	Barrick *et al.* 1988
2-Methylphenol	0.0072	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	0.01	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	0.063	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988
	0.072	AET	Maximum level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	>0.072	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	0.1	AET	LAET benthic community composition; 1% TOC (5)	Washington	Barrick *et al.* 1988
4-Methylphenol	0.12	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	0.36	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	0.67	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988
	0.67	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	1.2	AET	Maximum level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	2.5	AET	LAET benthic community composition; 1% TOC (5)	Washington	Barrick *et al.* 1988
Mineral oil	500	SB	Recommended target value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989
	3000	SB	Recommended directive value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989

Table G-1. Continued

Variable	Value ($\mu g \cdot g^{-1}$)*	Approach	Rationale	Jurisdiction	Reference
Mineral oil	5000	SB	Recommended limit value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989
Mirex	0.02	SB	U.S. Geological Survey sediment alert level (7)	United States	Pavlou and Weston 1983
Naphthalene	0.21	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	0.27	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	0.367	SLC	National screening level concentration for marine sediments @ 1% TOC	United States	Neff *et al.* 1986
	0.414	SLC	National screening level concentration for marine sediments @ 1% TOC; recalculated	United States	Neff *et al.* 1987
	0.5	EP	99th percentile chronic marine permissible concentration @ 1% TOC (6)	United States	Pavlou *et al.* 1987
	0.72	EP	95th percentile chronic marine permissible concentration @ 1% TOC (6)	United States	Pavlou *et al.* 1987
	0.99	AET	Interim criterion @ 1% TOC (1)	Washington	Washington Department of Ecology 1989
	1.7	AET	LAET benthic community composition; 1% TOC (5)	Washington	Barrick *et al.* 1988
	2.1	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988
	2.1	AET	Maximum level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	2.1	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	10.5	EP	EPA chronic marine threshold @ 1% TOC	United States	Bolton *et al.* 1985
	10.5	EP	EPA acute marine threshold @ 1% TOC	United States	Lyman *et al.* 1987
Nickel	14	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	20	SB	EPA Region V guideline for pollutional classification of sediments (9)	United States	Pavlou and Weston 1983
	25	SB	Ontario Ministry of the Environment dredge spoil guideline for open water disposal	Ontario	Fitchko 1989
	28	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	40	SB	Recommended target value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989
	45	SB	Recommended directive value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989

Table G-1. Continued

Variable	Value ($\mu g \cdot g^{-1}$)*	Approach	Rationale	Jurisdiction	Reference
Nickel	49	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	50	SB	EPA Region VI proposed guideline for open-water disposal	United States	Pavlou and Weston 1983
	100	SB	Recommended limit value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989
	120	AET	Maximum level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	>140	AET	LAET benthic community composition; dry weight (5)	Washington	Barrick *et al.* 1988
	140	AET	New LAET; dry weight (3,16)	Washington	Washington Department of Ecology 1988
	2000	SB	U.S. Geological Survey sediment alert level (7)	United States	Pavlou and Weston 1983
	NV (17)	AET	New LAET	Washington	Washington Department of Ecology 1989
Nitrobenzene	1.65	EP	EPA chronic marine threshold @ 1% TOC	United States	Bolton *et al.* 1985
N-Nitroso-diphenylamine	0.013	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	0.022	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	0.028	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988
	0.074	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	0.11	AET	LAET benthic community composition; 1% TOC (5)	Washington	Barrick *et al.* 1988
	0.11	AET	Interim criterion @ 1% TOC (1)	Washington	Washington Department of Ecology 1989
	0.22	AET	Maximum level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
Oil and grease	1000	SB	EPA Region V guideline for pollutional classification of sediments (9)	United States	Pavlou and Weston 1983
	1500	SB	Ontario Ministry of the Environment dredge spoil guideline for open-water disposal	Ontario	Fitchko 1989
	Narrative		Levels in sediments that cause deleterious effects to the biota should not be allowed	United States	U.S. EPA 1988
Organic materials	Narrative		Concentrations in marine sediments shall not be increased to levels that would degrade marine life	California	California State Water Resources Control Board 1989
Organohalogen compounds	Narrative		Limit of 0.01 parts of a concentration shown to be toxic to sensitive marine organisms in a bioassay sample and test carried out in accordance with procedures established or approved by the Minister	Canada	Ocean Dumping Regulations 1988b

Table G-1. Continued

Variable	Value ($\mu g \cdot g^{-1}$)*	Approach	Rationale	Jurisdiction	Reference
PAHs	3.8	SQT	No or minimal biological effects; naphthalene, chlorinated naphthalene, fluoranthene	United States	Chapman 1986
	3.8–6.8	SQT	Range of uncertain effects; naphthalene, chlorinated naphthalene, fluoranthene	United States	Chapman 1986
	6.8	SQT	Major biological effects; includes naphthalene, chlorinated naphthalene, fluoranthene	United States	Chapman 1986
PAHs — low molecular weight	0.61	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	2.4	AET	ACR NOEC; dry weight (2,19)	Washington	Washington Department of Ecology 1988
	3.7	AET	Interim criterion @ 1% TOC (1,19)	Washington	Washington Department of Ecology 1989
	5.2	AET	New LAET; dry weight (3,19)	Washington	Washington Department of Ecology 1988
	6.1	AET	Maximum level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	6.1	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	7.8	AET	LAET benthic community composition; 1% TOC (5)	Washington	Barrick *et al.* 1988
PAHs—high molecular weight	1.8	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	6.9	AET	ACR NOEC; dry weight (2,20)	Washington	Washington Department of Ecology 1988
	9.6	AET	Interim criterion @ 1% TOC (1,20)	Washington	Washington Department of Ecology 1989
	12	AET	New LAET; dry weight (3,20)	Washington	Washington Department of Ecology 1988
	51	AET	Maximum level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	>51	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	76	AET	LAET benthic community composition; 1% TOC (5)	Washington	Barrick *et al.* 1988
Parathion	0.02	SB	U.S. Geological Survey sediment alert level (7)	United States	Pavlou and Weston 1983
PCBs	0.004	SB	Recommended target value for classification of freshwater and dredged sediments for each individual compound; IUPAC numbers 28, 52, 101, 138, 153, 180	Netherlands	National Institute of Public Health and Environmental Protection 1989
	0.02	SB	Recommended target value for classification of freshwater and dredged sediments; sum	Netherlands	National Institute of Public Health and Environmental Protection 1989

Table G-1. Continued

Variable	Value ($\mu g \cdot g^{-1}$)*	Approach	Rationale	Jurisdiction	Reference
PCBs	0.02	SB	U.S. Geological Survey sediment alert level (7)	United States	Pavlou and Weston 1983
	0.03		Boundary Bay	British Columbia	Swain and Holms 1988
	0.03		Fraser River	British Columbia	Swain and Holms 1985
	0.03	SB	Recommended directive value for classification of freshwater and dredged sediments for each individual compound; IUPAC numbers 28, 52, 101, 138, 153, 180	Netherlands	National Institute of Public Health and Environmental Protection 1989
	0.0366	SLC	National screening level concentration for marine sediments @ 1% TOC; recalculated	United States	Neff *et al.* 1987
	0.0426	SLC	National screening level concentration for marine sediments @ 1% TOC	United States	Neff *et al.* 1986
	0.05			British Columbia	Pommen 1989
	0.05	SB	Ontario Ministry of the Environment dredge spoil guideline for open-water disposal	Ontario	Fitchko 1989
	0.07	EP	EPA chronic marine threshold @ 1% TOC; based on criterion for hexachlorobiphenyl	United States	Bolton *et al.* 1985
	0.1	SB	Recommended limit value for classification of freshwater and dredged sediments; IUPAC numbers 28, 52, 101, 138, 153, 180; individual	Netherlands	National Institute of Public Health and Environmental Protection 1989
	0.12	AET	Interim criterion @ 1% TOC (1)	Washington	Washington Department of Ecology 1989
	0.13	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	0.13	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988
	0.15	SB	Recommended directive value for classification of freshwater and dredged sediments; sum	Netherlands	National Institute of Public Health and Environmental Protection 1989
	0.31	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	0.4	SB	Recommended limit value for classification of freshwater and dredged sediments; sum	Netherlands	National Institute of Public Health and Environmental Protection 1989
	0.5	EP	Potential adverse effects on water quality (10)	Oregon	Oregon Department of Environmental Quality 1989a
	0.65	AET	LAET benthic community composition; 1% TOC (5)	Washington	Barrick *et al.* 1988
	1.1	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	2.5	AET	Maximum level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989

Table G-1. Continued

Variable	Value ($\mu g \cdot g^{-1}$)*	Approach	Rationale	Jurisdiction	Reference
PCBs	1–10	SB	EPA Region V guideline for pollutional classification of sediments (9,21)	United States	Pavlou and Weston 1983
	10		Maximum level for dredge removal/disposal	Japan	Japan Environment Agency 1987
PCB (1254)	0.1	SQT	No or minimal biological effects	United States	Chapman 1986
	0.1–0.8	SQT	Range of uncertain effects	United States	Chapman 1986
	0.418	EP	Interim mean criterion @ 1% TOC; based on Final Residue Value (8)	United States	U.S. EPA 1988
	0.8	SQT	Major biological effects	United States	Chapman 1986
Pentachlorophenol	0.069	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	0.14	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	>0.14	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	0.36	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988
	0.66	AET	LAET benthic community composition; 1% TOC (5)	Washington	Barrick *et al.* 1988
	Narrative	SB	The concentration of pentachlorophenol in sediments must not increase significantly with time (22)	Europe	Commission of the European Communities 1988
Phenanthrene	0.11	EP	99th percentile chronic marine permissible concentration @ 1% TOC (6)	United States	Pavlou *et al.* 1987
	0.24	EP	95th percentile chronic marine permissible concentration @ 1% TOC (6)	United States	Pavlou *et al.* 1987
	0.259	SLC	National screening level concentration for marine sediments @ 1% TOC	United States	Neff *et al.* 1986
	0.32	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	0.368	SLC	National screening level concentration for marine sediments @ 1% TOC; recalculated	United States	Neff *et al.* 1987
	0.69	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	1	AET	Interim criterion @ 1% TOC (1)	Washington	Washington Department of Ecology 1989
	1.02	EP	Interim mean criterion @ 1% TOC; based on Final Chronic Value (8)	United States	U.S. EPA 1988
	1.5	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988
	3.2	AET	Maximum level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989

Table G-1. Continued

Variable	Value ($\mu g \cdot g^{-1}$)*	Approach	Rationale	Jurisdiction	Reference
Phenanthrene	3.2	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	4.8	AET	LAET benthic community composition; 1% TOC (5)	Washington	Barrick *et al.* 1988
	14	EP	Safe level predicted from acute water quality criterion @ 1% TOC	United States	Pavlou 1987
	14	EP	EPA chronic marine threshold @ 1% TOC	United States	Bolton *et al.* 1985
	14	EP	EPA acute marine threshold @ 1% TOC	United States	Lyman *et al.* 1987
Phenol	0.12	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	0.12	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	0.42	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988
	1.2	AET	Maximum level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	>1.4	AET	LAET benthic community composition; 1% TOC (5)	Washington	Barrick *et al.* 1988
Plastics	4%		By volume; and other persistent synthetic materials, in a suitably comminuted form	Canada	Ocean Dumping Regulations 1988b
Pyrene	0.43	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	0.434	SLC	National screening level concentration for marine sediments @ 1% TOC	United States	Neff *et al.* 1986
	0.665	SLC	National screening level concentration for marine sediments @ 1% TOC; recalculated	United States	Neff *et al.* 1987
	0.85	SB	99th percentile chronic marine permissible concentration @ 1% TOC (6)	United States	Pavlou *et al.* 1987
	1.6	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	1.9	SB	95th percentile chronic marine permissible concentration @ 1% TOC (6)	United States	Pavlou *et al.* 1987
	2.6	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988
	7.3	AET	Maximum level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	>7.3	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	10	AET	Interim criterion @ 1% TOC (1)	Washington	Washington Department of Ecology 1989
	13.11	EP	Interim mean criterion @ 1% TOC	United States	U.S. EPA 1988

Table G-1. Continued

Variable	Value ($\mu g \cdot g^{-1}$)*	Approach	Rationale	Jurisdiction	Reference
Pyrene	14	AET	LAET benthic community composition; 1% TOC (5)	Washington	Barrick *et al.* 1988
	49.5	EP	Safe level predicted from acute water quality criterion @ 1% TOC	United States	Pavlou 1987
	49.5	EP	EPA chronic marine threshold @ 1% TOC	United States	Bolton *et al.* 1985
	49.5	EP	EPA acute marine threshold @ 1% TOC	United States	Lyman *et al.* 1987
Radioactive matter	Narrative		0.000 05 $TBq \cdot kg^{-1}$ for alpha emitters	Canada	Ocean Dumping Regulations 1988b
	Narrative		0.02 $TBq \cdot kg^{-1}$ for beta/gamma emitters with half-lives of greater than 1 year; excluding tritium	Canada	Ocean Dumping Regulations 1988b
	Narrative		3 $TBq \cdot kg^{-1}$ for tritium and beta/gamma emitters with half-lives of 1 year or less	Canada	Ocean Dumping Regulations 1988b
Silver	6.1	AET	Interim criterion; dry weight (1)	Washington	Washington Department of Ecology 1989
	0.59	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	1.2	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	5.2	AET	Maximum level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	5.2	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	5.9	AET	New LAET; dry weight (3,23)	Washington	Washington Department of Ecology 1988
	>6.1	AET	LAET benthic community composition; dry weight (5)	Washington	Barrick *et al.* 1988
	1000	SB	U.S. Geological Survey sediment alert level (7)	United States	Pavlou and Weston 1983
Sulphide, dissolved	Narrative	SB	Concentration of waters in and near sediments shall not be significantly increased above that present under natural conditions	California	California State Water Resources Control Board 1989
2,4,5-TP	0.02	SB	U.S. Geological Survey sediment alert level (7)	United States	Pavlou and Weston 1983
Tetrachloroethene	0.014	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	0.014	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	0.057	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988
	0.14	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	0.21	AET	Maximum level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	>0.22	AET	LAET benthic community composition; 1% TOC (5)	Washington	Barrick *et al.* 1988

Table G-1. Continued

Variable	Value ($\mu g \cdot g^{-1}$)*	Approach	Rationale	Jurisdiction	Reference
Tetrachloroethene	NV (17)	AET	New LAET	Washington	Washington Department of Ecology 1989
Tetrachloroethylene	0.45	EP	EPA chronic marine threshold @ 1% TOC	United States	Bolton *et al.* 1985
Toluene	2.5	EP	EPA chronic marine threshold @ 1% TOC	United States	Bolton *et al.* 1985
Toxaphene	0.001 ppb	EP	99th percentile chronic marine permissible concentration @ 1% TOC (6)	United States	Pavlou *et al.* 1987
	0.002 ppb	EP	95th percentile chronic marine permissible concentration @ 1% TOC (6)	United States	Pavlou *et al.* 1987
	0.02	EP	U.S. Geological Survey sediment alert level (7)	United States	Pavlou and Weston 1983
1,2,4-Trichlorobenzene	0.0064	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	0.0064	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	0.0081	AET	Interim criterion @ 1% TOC (1)	Washington	Washington Department of Ecology 1989
	0.031	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988
	0.064	AET	Maximum level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	0.064	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
Trichloroethylene	1.6	EP	EPA chronic marine threshold @ 1% TOC	United States	Bolton *et al.* 1985
Xylenes	0.012	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	0.012	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	0.04	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988
	0.12	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	>0.12	AET	LAET benthic community composition; 1% TOC (5)	Washington	Barrick *et al.* 1988
	0.16	AET	Maximum level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	NV (17)	AET		Washington	Washington Department of Ecology 1989
Zinc	75	SB	EPA Region VI proposed guideline for open-water disposal	United States	Pavlou and Weston 1983
	90	SB	EPA Region V guideline for pollutional classification of sediments (9)	United States	Pavlou and Weston 1983
	100	SB	Ontario Ministry of the Environment dredge spoil guideline for open-water disposal	Ontario	Fitchko 1989

Table G-1. Continued

Variable	Value ($\mu g \cdot g^{-1}$)*	Approach	Rationale	Jurisdiction	Reference
Zinc	160	AET	Screening level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	160	AET	ACR NOEC; dry weight (2)	Washington	Washington Department of Ecology 1988
	190	EP	EPA chronic marine threshold @ 1% TOC	United States	Bolton *et al.* 1985
	250		Potential adverse effects on water quality (10)	Oregon	Oregon Department of Environmental Quality 1989a
	260	AET	LAET benthic community composition; dry weight (4)	Washington	Beller *et al.* 1986
	300	SB	Recommended target value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989
	410	AET	LAET benthic community composition; dry weight (5)	Washington	Barrick *et al.* 1988
	410	AET	New LAET; dry weight (3)	Washington	Washington Department of Ecology 1988
	560	EP	EPA acute marine threshold @ 1% TOC	United States	Lyman *et al.* 1987
	1000	SB	Recommended directive value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989
	1600	AET	Maximum level for dredge disposal	Washington	Puget Sound Dredged Disposal Analysis 1989
	2500	SB	Recommended limit value for classification of freshwater and dredged sediments	Netherlands	National Institute of Public Health and Environmental Protection 1989
	5000	SB	U.S. Geological Survey sediment alert level (7)	United States	Pavlou and Weston 1983

(1) These values were established by both the AET and equilibrium partioning methods, along with recommendations by the United States EPA Scientific Advisory Board.

(2) The ACR NOEC; dry weight (1) Effects Concentration (NOEC) represents recommended Option 2 in "Draft Contaminated Sediments Criteria Report", August 1988, prepared by PTI Environmental Services for the Washington Department of Ecology. Option 2 recommends applying the ACR value (10) to the highest AET value or using the Benthic AET value, whichever is lower. The recommended ACR of '10' is consistent with U.S. EPA recommendations for complex effluents contained in "Technical support document for water quality-based toxics control, 1985, EPA/440/4-85-032, U.S. EPA Office of Water, Washington D.C.".

(3) The New LAET (Lowest Apparent Effects Threshold) values include the Microtox AET and are identified in Table 2 of "Sediment Quality Values Refinement: Tasks 3 & 5, 1988 Update and Evaluation of Puget Sound AET", dated June 1988, prepared by PTI Environmental Services for the Puget Sound Estuary Program of the United States Environmental Protection Agency, Region 10.

(4) Based on 94 stations. A ">" value indicates that a defined AET could not be established because there were no "effects" stations with chemical concentrations above the highest concentration among "no effects" stations.

(5) Based on 201 stations. A ">" value indicates that a defined AET could not be established because there were no "effects" stations with chemical concentrations above the highest concentration among "no effects" stations.

(6) Permissible contaminant concentration values were based on chronic water quality criteria estimated from acute criteria.

(7) In order that potential sites of concern may be identified, 15-20% of the samples were flagged.

(8) The Final Chronic Value (FCV) is the concentration protecting aquatic life from chronic toxicity. The Final Residue Value (FRV) is the concentration protecting uses of aquatic life, including marketability based on the FDA or other action levels, or consumption of aquatic life by wildlife. PCB criteria are based on the 1980 FDA action level of 5 mg/kg and bioaccumulation factors measured in the laboratory. Since 1980, the FDA action level has been changed to 2 mg/kg. Furthermore, the residue values do not account for bioaccumulation in the food chain which results in a bioaccumulation factor for fish at least 10 times higher than those measured in the laboratory.

(9) Levels shown were regarded as the cut-off value between non-polluted and moderately polluted sediments. These guidelines were recommended for use only as a tool in making a subjective judgement as to suitability of dredge material for open water disposal. In the case of mercury and PCB, violations of guidelines were considered irrefutable evidence of severe pollution and therefore, sediments were unsuitable for open water disposal.

(10) Where the natural quality of sediment for the waterbody exceeds the guideline numerical limit for a metals parameter, the natural sediment quality shall be the guideline numerical limit. A natural sediment quality guideline for a waterbody will be applicable only for that specific waterbody.

(11) This ACR value was established by the Benthic Apparent Effects Threshold value per the recommendations of Option 2.

(12) Quality objectives refer to the [illegible]etic mean of the results obtained over a year. Samples must be taken at a point sufficiently close to the discharge point to be representative of the quality of the aquatic environment in the area affected by the discharges, and the frequency of sampling must be sufficient to show any changes in the aquatic environment, having regard in particular to natural variations in hydrological conditions.

(13) Permissible contaminant concentration values were based on the Environmental Protection Agency's chronic water quality criterion or an EPA suggested value.

Table G-1. Continued

(14) The term chlorophenol means the sum of tri-, tetra-, and pentachlorophenol which may be present in water, sediment or fish. The maximum value should not be exceeded in bottom surface sediments taken in any part of the sub-basin, except in the initial dilution zones of effluent. The average of at least three replicate sediment samples taken from the same site should be used to check the objective. The objective applies only to fish muscle tissue, not the whole fish or organs of a fish, of any species caught in any part of the sub-basin, including the initial dilution zones of effluents.

(15) Standstill: the concentration of DDT in the aquatic environment, sediments and/or molluscs and/or shellfish and/or fish must not increase significantly with time. The sum of the isomers 1,1,1-trichloro-2,2 bis(p-chlorophenyl) ethane; 1,1,1-trichloro-2 (o-chlorophenyl)-2- (p-chlorophenyl) ethane; 1,1,1-dichloro-2,2 bis (p-chlorophenyl)ethylene, and 1,1,1-dichloro-2,2 bis (p-chlorophenyl) ethane.

(16) A definitive AET could not be established for any biological indicator. The NOEC was set at the chemical concentration represented by the lowest 'greater than' value for the AET.

(17) "NV" indicates that a definitive AET could not be established because there were no 'biological effects' stations with chemical concentrations above the highest concentration among 'no effects' stations (also known as the 'greater than' or 'indefinite' AETs). These chemicals are recommended for routine analysis in Puget Sound sediments. Specific criteria may be established for these chemicals before adoption of the sediment quality standards.

(18) S = 10; no fishing operation is conducted = 50; fishing operations are conducted, and where such fishery products feed on living things in/on bottom sediments, accounting for < 50% of the total catches = 100; fishing operations are conducted, and where such fishery products feed on living things in/on bottom sediments, accounting for > 50% of the total catches.

(19) This criterion is applicable to the sum of the following 'low molecular weight' polynuclear aromatic hydrocarbon compounds: naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, and anthracene.

(20) This criterion is applicable to the sum of the following 'high molecular weight' polynuclear aromatic hydrocarbons: fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzofluoranthenes, benzo(a)pyrene, indeno(1,2,3-c,d)pyrene, dibenzo(a,h)anthracene, and benzo(g,h,i)perylene.

(21) Sediments with PCB concentrations between 1 and 10 were considered on a case by case basis. Sediments with greater than 10 ppm PCB were considered grossly polluted.

(22) Standstill: the concentration of PCP in sediments and/or molluscs and/or shellfish and/or fish must not increase significantly with time.

(23) The LAET for this chemical parameter was based on a biological indicator with a definitive AET not represented by a "greater than" value.

Appendix H
Members of the Interdepartmental Working Group on Marine Environmental Quality Guidelines

APPENDIX H. MEMBERS OF THE INTERDEPARTMENTAL WORKING GROUP ON MARINE ENVIRONMENTAL QUALITY GUIDELINES

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Appendix I
Members of the Canadian Council of Ministers of the Environment Task Group on Water Quality Guidelines

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